A DESCRIPTION OF DETERMINANTS OF THE AVERAGE PHYSICAL PRODUCT OF LABOR FOR THE LIGNITE COAL SURFACE MINING INDUSTRY OF NORTH DAKOTA

by

Jeffrey K. Struck

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This Thesis submitted by Jeffrey K. Struck in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

[Signatures]

[Signature]
(Chairman)

[Signature]
Fredrick E. Peterson

[Signature]
Jest A. Strickley

[Signature]
Dean of the Graduate School
Permission

Title A Description of Determinants of the Average Physical Product of Labor for the Lignite Coal Surface Mining Industry of North Dakota

Department Economics

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ABSTRACT

The increasing demand for oil and gas is causing renewed interest in the use of coal as an alternative fuel. The anticipated redevelopment of the coal industry will directly affect local coal areas and surrounding regions by creating population and income changes attributable to labor migration. State and local government will be confronted with increased demand for roads, schools, and public services because of the migration. The ability to predict these demands based on information about coal reserve and mining company characteristics would be valuable for effective governmental planning. This study initiates work towards this goal by investigating the determinants of the average physical product of labor and differential rents captured by the discriminative selection of coal reserves. This effort is specifically for the State of North Dakota.

This study is a practical, theoretical, and analytical investigation emphasizing the factors of production (land, labor, and capital) with particular interest in detecting changes in the labor-capital mix when confronted by variable land. Chapter II provides practical background information concerning the development of the North Dakota coal industry. The theoretical investigation of Chapter III explores production theory applicable to the surface coal mining environment including Ricardian theory of rent, discriminative selection of resources, and the producers production set. The analytical investigation of Chapters IV and V are specific attempts to discover the determinants of the average physical product of labor and verify the capture of Ricardian rents by x
mining companies in the North Dakota surface coal mining industry. The methods of analysis used involve literature survey, tabular data, and descriptive statistics consisting of simple linear regression and chi square test for interdependence. Chapter VI provides a summary and makes practical suggestions for professional economists, the coal mining industry, and the State of North Dakota.

Results of this investigation indicate, first, that overburden thickness is the strongest indicator of labor productivity. An intermediate factor (stripping machine size) appears to be important. As the overburden thickness increases, a larger machine is employed for coal extraction causing a higher average physical product of labor.

Second, the investigation indicates that Ricardian rents are being captured by the larger mining companies through the practice of discriminative selection of reserves. Larger companies obtain thicker coal seams, thinner overburden, and utilize larger, but not the largest, extraction equipment available. This results in larger companies operating with higher-than-average labor productivity.

This study determines that geological characteristics affect labor productivity and cause mining companies to discriminately select coal reserves. The study does not predict labor demand based on resource characteristics; however, it does prepare groundwork in that direction. The results invite further study in the North Dakota lignite industry to develop the industry production function to allow the prediction of labor demands.
CHAPTER I

INTRODUCTION

Since the Arab oil embargo of 1973, the United States has been made aware of the decreasing availability of easily obtained fuels. Serious investigation of the problem reveals the fact that industry cannot long rely on clean, easily burned gas and oil. Alternative sources of energy must be utilized to help avoid problems of diminished petroleum supplies. The best, most easily exploited alternative fuel is coal. As a result, the United States coal industry is undergoing tremendous expansion.

An important segment of the expanding coal industry is the lignite industry. Because lignite coal is found at relatively shallow depths of twenty to 120 feet, it can be safely mined utilizing surface mining techniques. The clean-burning characteristic of lignite, relative to other coals, requires that less extensive pollution control equipment need be installed by the consuming facility. The minimizing of transportation cost through mine-mouth consumption arrangement makes use of the low B.T.U. content of lignite coal economical for electrical power generation. Recent developments in coal gasification will make lignite an important substitute for natural gas. The potential for the liquifaction of lignite exists. Together, these factors make for an optimistic market demand forecast for lignite coal.
More than one-third of the land area of North Dakota is underlain by lignite reserves; therefore, lignite is becoming one of the major resources in the State. Expansion of the industry is inevitable, especially in electrical generation and coal gasification. New mines are being opened which will provide occupational opportunities and income sources for the western communities of North Dakota. The impacts which accompany rapid population growth attributable to the migration of mine and power plant employees will present considerable problems for state and local government. Problems will be especially evident in the area of traditional state expenditures such as roads, schools, education, and public services, as well as in the associated area of tax planning.

The increasing importance of lignite as an alternative fuel and the expected growth of the North Dakota branch of the industry, in addition to the need for better information about local and regional impacts, necessitates an examination of the economics of the surface mining industry. By comparison, the underground mining industry of the United States has been studied at length with respect to the previously mentioned topics of concern. Consequently, more definitive information is known about the effects of growth in the deep mining industry than the surface mining industry. This study represents the initiation of an effort to learn more of the effects of growth in the surface mining industry, especially within the context of the North Dakota lignite industry.
Scope of Study

The scope of this study is intended to provide balanced practical and theoretical research of the strip mining industry in North Dakota. The study begins with a historical and practical presentation of lignite coal mining in North Dakota. It examines the coal extraction process and describes current production trends in the industry. The theoretical aspects of coal mining are then presented using fixed proportions production concepts. The discussion particularly focuses on the interrelatedness of the factors of production (land, labor, and capital) and how they are determinants of the average physical product of labor.

The analytical portion of the study accomplishes two major functions. First, qualities of the factors of production are evaluated to determine which are the best predictors of labor productivity. The interest in labor productivity is based on evidence that it is important for the eventual forecasting of labor demands, as well as the fact that the average product of labor is the only meaningful measure of production for which there is data. Second, North Dakota mining companies are evaluated to determine if they capture Ricardian rents through the process of discriminative selection of coal reserves. This is also important to the eventual prediction of labor demands based on evidence that companies of different sizes obtain different labor productivity. Both functions incorporate the use of theoretical principles and production data.

Surface mining of lignite is studied to reflect the needs of the State of North Dakota since all coal mining in the State utilizes this extraction technique.
This investigation fills a void in existing coal research where underground mining techniques and trends have been studied at length.

**Goals**

This study represents an effort to accomplish three major goals. First of these is to determine the relationship between characteristics of the factors of production (land, labor, and capital) and the average physical product of labor. To this end, thickness of coal seams, overburden thickness, machinery indexes, and mining company organization types are statistically compared to calculated labor productivity data. The results will indicate those characteristics which best explain and thus predict labor productivity.

Second, characteristics of land, labor, and fixed capital are compared with a classification of company organization types to determine if the Ricardian theory of differential rent applies to resource acquisition therefore affording improved labor productivity. More specifically, this investigation will determine if the discriminative selection of factors of production provides advantageous market positions to some mining companies. Third, the format of this study is arranged such that it may provide a comparison to various studies of underground bituminous extraction, especially to emphasize dissimilarities.

**Delimitation**

This investigation is limited to the lignite industry of North Dakota. The information and data contained in the study are based on the statistical population of the State; therefore, results are of a descriptive nature. The North Dakota
lignite industry may be similar to those of other states, and this study may be used as a model for further investigations in those areas. The statistical results, however, because they are based on the population of North Dakota mines rather than a random statistical sample of all United States surface mines, are limited in their abilities to make inferences about surface mines in general.

This study does not develop the industry production function for North Dakota. The nature of the data and facilities available prohibit this from being accomplished. This research deals with determinants of labor productivity. Productivity may be defined as a measurement of work. Productivity is a ratio of combined resources which results in a final product. Knowing how changes in factors of production affect productivity is important to the development of our understanding of how these resources intermingle to determine average product. This knowledge of productivity can eventually be used to predict labor requirements of the mines and, in turn, population impacts. While this study does not undertake the latter tasks, it certainly lays the essential groundwork for such an investigation.

Data Source

The preparation of this study requires information concerning mineral geology, coal production, labor productivity, and the structure of the lignite mining companies in North Dakota. Geological data is obtained primarily from the North Dakota Geological Survey and its publications. The information provides data on overburden thickness, coal seam thickness, etc.
mine locations. Specific information of overburden thickness and coal seam structure is verified by interview with representatives of the coal mining companies.

Coal production data is available from North Dakota State Coal Mine Inspection Department Reports. These reports provide information concerning the number of days each mine operated during the year, the number of employees, and annual production figures. To fill information gaps and to obtain knowledge of individual mine operations, the company representatives were interviewed.

Labor productivity is calculated from information obtained in the State Coal Mine Inspection Department Reports and from data presented in the United States Department of Interior Minerals Yearbook, 1955 through 1975.

Historical information of the State mining industry is obtained primarily from the book One Time Harvest by Mike Jacobs. Other literature which provide structure for this study are basically in three volumes. One is a fifty-year study of the United States coal development 1903 to 1953 by H. E. Risser. The second is a more recent study of the redevelopment of the bituminous coal industry of the United States by C. L. Christenson. A third study, which provides detail of production theory as it applies to the deep mining industry of Utah, is the doctoral dissertation of S. A. Stradley.

**Methodology**

Methods of analysis used in the study involve literature survey, tabular data, and descriptive statistics. Historical reviews and literature of production
theory provide a basis for explaining trends and predicting relationships of the factors of production. Tabulated data is useful for explaining trends in labor productivity. The descriptive statistics used in the study are simple linear regression and chi square. The statistical analysis is descriptive rather than inferential because the data base is the North Dakota population rather than a random sample of all U.S. surface mines. The statistical techniques are used to compare geological and industry characteristics with labor productivity data. Company characteristics are compared to geographical, geological, and equipment data. Statistical and data analysis are not considered ends to themselves. Because of inherent problems which distort results, they are used only as indicators of probable conditions which appear to be present in the lignite industry.

**Plan of Study**

Chapter II is a survey of key concepts present in the surface coal mining industry. It describes lignite coal and its occurrence in North Dakota geology. The history of surface mining in the State, as well as examples of typical mining operations, are presented. The chapter is concluded with a discussion of trends found in surface mining production and mine safety. Chapter III is a review of production theory as applied to the surface mining extraction process and the principle factors of production. The chapter is concluded with a review of three major studies of the economics of coal extraction. The findings of these studies and their limitations are discussed in the context of the North Dakota lignite industry.
Chapter IV explains the research model. First, the factors of production are presented and the hypotheses of how these factors predict labor productivity are developed. Secondly, it presents the hypothetical basis for the investigation of economic rents captured by mining companies. Chapter V is a statistical presentation of the hypothesized relationships described in Chapter IV. Chapter VI contains conclusions of the study and policy recommendations for North Dakota and the lignite industry.

Review of Findings

The major findings of this study pertain, first, to the determinants of the average physical product of labor and, second, to the detection of industry conformance to the theory of discriminative selection of factors of production. Important facts concerning labor productivity, safety, and operational efficiency of the strip mining technique explain why surface coal mining dominates the coal industry. This extraction technique provides an increase in labor productivity and safer working conditions for miners. Larger stripping machinery is being selected to provide economies of scale for coal production and mine-mouth power generation facilities.

Overburden thickness proved to be the strongest indicator of labor productivity among the geological characteristics tested. The results of the study show that thick overburdens and increased demand necessitate the use of larger stripping machinery which, in turn, is associated with higher labor productivity. Coal seam thickness represents a weak indicator of labor productivity as opposed to studies of underground mining techniques which
showed a stronger association. Market and geological factors affecting stripping machine size, therefore, appear to provide the greatest influence on the average product of labor.

The investigation of discriminative selection in lignite surface mining indicates larger companies are able to capture Ricardian rents. Specifically, larger companies tend to control reserves which contain thicker coal seams, thinner overburdens, and are, therefore, able to utilize more efficient resource extraction techniques than smaller companies. Consequently, larger companies tend to have higher average products of labor and stronger economic positions in the coal market.

Overall, results tend to indicate that the geological configurations of the coal reserves determine the type of company which is likely to mine the resource. Ideal geological conditions are likely to attract large efficient companies. Labor employed in the strip mines, then, is selected according to the demand for coal and the reserve characteristics. High labor productivity effectively reduces the amount of labor utilized in the extraction technique; however, high mine output requires more labor. Likewise, if a small company proposed to mine a reserve and supply a small demand for coal, the lower labor productivity results in a greater requirement for labor, but low output requires less labor. The factors of production, coupled with the type of company attracted to the reserve, determine the productivity of labor. Further study can translate the resulting level of labor productivity into a specific labor demand.
CHAPTER II

A DESCRIPTION OF STRIP MINING

Introduction

This chapter contains a basic overview of the surface mining process, especially for North Dakota lignite. It surveys lignite resources, mining history, and the coal mining process to allow better understanding of production trends. The chapter first looks at lignite, where it is found in North Dakota and its characteristics. A brief history of the North Dakota mining industry follows. Next, mining equipment and its use is considered. Two typical mines are presented, and labor productivity trends are discussed.

A Look at the Resource

Geologically speaking, lignite is a young coal. Consequently, it is the lowest rank of all types of coal available. Coals are ranked according to several basic characteristics: moisture content, volatile matter (gases), and fixed carbon (a determinate of B.T.U. content). These qualities vary according to the metamorphic state of the coal. Grade of coal refers to the presence of impurities, specifically sulfur and ash. (U.S. Geological Survey et al., 1973) Table 1 illustrates the relative ranking of lignite and how it compares with other coals in B.T.U. content.
### TABLE 1

**APPROXIMATE RANKING OF COALS BY PER CENT CONTENT OF MOISTURE, VOLATILES, AND FIXED CARBON AND B.T.U. PER POUND OF DRY COAL.**

<table>
<thead>
<tr>
<th>Type of Coal</th>
<th>Per Cent of Total Content</th>
<th>B.T.U./lb. of Dry Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture</td>
<td>Volatile</td>
</tr>
<tr>
<td>Meta-anthracite</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Anthracite</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Semianthracite</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Low-volatile bituminous</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>Medium-volatile bituminous</td>
<td>6</td>
<td>26</td>
</tr>
<tr>
<td>High-volatile A bituminous</td>
<td>5</td>
<td>37</td>
</tr>
<tr>
<td>High-volatile B bituminous</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>High-volatile C bituminous</td>
<td>17</td>
<td>39</td>
</tr>
<tr>
<td>Subbituminous A</td>
<td>17</td>
<td>40</td>
</tr>
<tr>
<td>Subbituminous B</td>
<td>25</td>
<td>34</td>
</tr>
<tr>
<td>Subbituminous C</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Lignite A</td>
<td>45</td>
<td>25</td>
</tr>
<tr>
<td>Lignite B (Leonardite)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>


*a* Leonardite is oxidized or slack lignite. It is mined as a water additive in petroleum drilling operations.

*b* Not available.
It is apparent from the table that lignite is low in fixed carbon (B.T.U. content) and high in moisture; the volatile level is somewhat low. This means less polluting gas is released during combustion allowing for less expensive emission control for consuming facilities. The high moisture content directly affects the economics of lignite transportation. Lignite characteristically stores poorly as it oxidizes quickly when exposed to air and is subject to spontaneous combustion, otherwise known as "the heat of wetting." The main coal impurities are sulfur and ash. North Dakota lignite is of relatively better quality than other coal produced in the United States as sulfur and ash content are below average at 0.7 per cent and 6.7 per cent respectively. (U.S. Geological Survey et al., 1973) Almost 40 per cent of United States surface mined coal has over 1.0 per cent sulfur. (King Lin, 1977)

Lignite can be found in various strata covering more than one-third of the State land area (see Figure 1). Not all lignite-bearing areas can be mined due to limitations of technology, land acquisition, and geology. Nearly all the minable lignite in North Dakota is found in the Fort Union formation of the Paleocene age. This formation contains the Ludlow member, Tongue River member, and the Sentinel Butte member. The Ludlow member, being the deepest, has limited outcroppings in Golden Valley county and stretches across Slope and Bowman counties into Adams county. The coal occurs in thin layers and reaches a total thickness of thirty-nine feet eleven inches. The available lignite is limited.

The Tongue River member is the largest deposit. It covers nine-tenths of the lignite-bearing areas in North Dakota. This member is as thick as
(b) Location of Lignite-bearing Strata in North Dakota

KEY
- Lignite bearing strata
- Omitted due to insufficient data
- Area containing lignite beds 2½ feet thick or less
- Known strippable lignite deposits
- Area covered by geological cross-section


Fig. 1. Location of Lignite in North Dakota
1,100 feet and as thin as 500 feet. The Sentinel Butte member is shallower, and its lignite-bearing area is small. (Brant, 1953) Lignite occurs randomly in these formations as lenses which extend for a distance and disappear to reappear again in other areas. Currently, surface mines reach only the highest lignite deposits of these reserves.

As technology improves, mining companies may be able to obtain cheaper coal. Much of the earth above the coal deposits is unconsolidated sand and clay which is easily removed by large earth-moving equipment. The unconsolidated earth (overburden) makes underground mining inappropriate. Hazards of cave-in and subsidence are too great.

In addition to the designated known strippable reserves are areas of less well-defined, equally abundant, reserves. Total lignite reserves are estimated to be 350.9 billion tons of which 19 billion tons are considered strippable. (Jenkins, 1974)

North Dakota Mining History

Earliest records of lignite use in North Dakota are contained in Lewis and Clark’s journals. The Indians were aware of the black substance and rarely used it. Current archeological diggings have uncovered only rare signs of coal being burned in campfires. Lewis and Clark wrote of repairing Indian tomahawks over a lignite-fired forge in 1804. Comments were made by other writers by 1867. In particular, a steamship captain made notes in his log observing how coal taken from exposed veins burned cleaner and better than coal taken from greater depths. Apparently the use of lignite as a fuel
was not accepted even as late as 1905 when records show ranchers preferred to purchase eastern coal because of its high heat content. It is noted, however, that lignite was dug for heating by new cattle ranchers in a money-saving effort. Conventional stoves did not burn lignite well as the small fire boxes were designed for hard eastern coal. A new stove was designed in 1890 which burned lignite well, causing lignite boosters to forecast great development in western North Dakota. (Jacobs, 1975)

Several promoters attempted to develop town sites, promising rapid growth and prosperity, with lignite being the prime industrial attraction. The names reflected the enthusiasm. Dunseith was called "the little Chicago of the west." The town of Energy survived one winter. Others were called Miner, Atcoal, Coalbank, Coal City, and Coal Harbor. The first stable mining ventures were administered by Northern Pacific Railroad to fill its own needs. By 1920, there were three bona fide coal towns: Scranton, Lehigh, and Wilton. These towns still represent major lignite areas of North Dakota. Lignite mining had become a stable industry and marketing promised to be big business. (Jacobs, 1975)

The early mines in North Dakota were underground, using room and pillar techniques. Picks and shovels were used to dig the coal. Marketing was simple. The customers would back their own wagons into the drift or slope mine for loading. Technology improved with mines becoming more mechanical. Tracks were laid to the mines, and heating coal demand was replaced by commercial demand. The lignite was shipped to provide heat for governmental
institutions. By 1915 a state-owned mine was providing fuel to a generating plant which provided power for irrigation pumps on the Missouri River. The State of South Dakota bought a mining company in 1920 to provide lignite for its state institutions. This represented the establishment of lignite as a prime energy source in the region.

Before 1910, horse-drawn scrapers performed stripping operations. In 1925, a Dickinson mining company bought a large excavating shovel which had been used in the construction of the Panama Canal. (Jacobs, 1975) This started a trend of larger stripping machinery that proved more economical and safer than underground techniques. The combination of high miner fatality rates and inability to supply adequate quantities of coal caused the decline of deep mining. Instability of the clay and sand overburden caused frequent roof collapses. Dangerous mine gases were not present; however, large amounts of coal had to be left in the mine to support the roof. Mining inefficiencies hastened the decline of deep mining. By 1955, all operating mines employed stripping techniques.

Transportation and Markets

The facts that lignite has low heat value, is almost 40 per cent water, and stores poorly due to its tendency to oxidize or spontaneously ignite have retarded the growth of the lignite industry. Consequently, its uses have remained local until recent years. After wagon transportation, the railroad provided economical transportation for the coal. Unit trains, containing only lignite as cargo, provide continued efficiencies despite rising costs. By
maintaining the integrity of the train from mine to destination, rapid loading and unloading facilities may be used. The coal slurry may soon compete with the railroad in long distance coal transportation. Specially prepared lignite is pumped through pipelines with water as a carrier. Lignite must be dried before use regardless of the type of transportation used; therefore, the only disadvantage of slurry lines might be inflexibility in choosing a destination point.

Often, the least expensive means of transporting lignite is to convert it into a different form of energy at the mine and transport it as electricity or synthetic natural gas. This fact increases the development potential of the mine-mouth operation in which a power plant or gasification plant is co-located with the mine. Economies presented by this system have been important in shifting consumption of lignite away from home heating to large-scale power generation. This shift has forced many small mines to close. While there were almost a hundred mines operating during peak years of the lignite mining, now there are ten. The trend toward co-location and lignite transformation will undoubtedly continue.

Productivity

Certain geological and economic elements must be considered before lignite mining operation can begin. These elements affect equipment selection and mining strategy used during the course of movement through a reserve. All of these factors eventually affect production and productivity of the mine.
As with other producers, the ultimate goal of mining is to minimize unit costs of production.

**Process Assessment**

Lignite coal mining is actually an earth-moving operation not unlike highway, canal, or tunnel construction. Similar technologies are involved. The geology of the reserve is most important to the mining process and must be properly assessed and monitored before and during the mining procedure. Once a reserve has been obtained by lease or purchase, extensive core sampling is done to identify shape and characteristics of the coal seams. Drillings are made along standard section and quarter lines, as these are convenient guide lines for laying out mining movement. (Van Sant, 1958) Core samples indicate the type and thickness of overburden, thickness and quality of the coal, locations of parting materials between coal seams, and soil layering. From this data, the decision to strip mine or deep mine is made. Only strip mining is considered in North Dakota due to the unconsolidated overburden, low cost, and proximity of good reserves of lignite to the surface.

The geological information is then combined with production requirements as determined by demand and analyzed to determine proper machinery specifications so as to insure an economical investment. Characteristics to be considered in the case of a stripping machine are bucket size, effective dumping reach and height, treading pressure, and cycle rates. The analysis has proven valuable by ensuring that the equipment selected will be optimally utilized. Analysis may be continued after mining has begun. This provides
continuous monitoring of production in the face of changing geological characteristics and changing demand. (Stefanko, 1973) Due to lignite perishability, production levels are dictated by current demand.

A series of mathematical formulas is available to predict output given certain mine and equipment characteristics. Critical factors are stripper performance data, swell characteristics of the overburden, depth of overburden, thickness of the coal seam, angle of repose of the spoil pile, and work schedule. (Stefanko, 1973) One must estimate the parameters of the model to determine if production will be adequate.

Machinery

Following a thorough geological investigation of the reserve, the machinery used for stripping is purchased. The collective data and production requirements are utilized by the steam shovel manufacturers to design the most efficient configuration for the individual mines. Because of their immense size, strippers generally are assembled at the mine to remain in operation until the mine is closed and reclaimed. Small mines have been known to utilize conventional earth-moving equipment due to cost savings features of lease contracts and service contracts.

Different types of stripping machines have been used. The first stripper used in North Dakota was the horse-drawn scraper with a moving capacity of one-third to one-half cubic yard of earth. This implement proved inadequate and was replaced by fully mechanized devices. One mine operator in North Dakota continues to use this technique by employing a Caterpillar 637-D pan
scraper with a capacity of thirty-five to forty cubic yards (see Figure 2a).

Using these in groups of six, he is capable of moving overburden as quickly as the largest draglines in the State.

The first large-scale excavating device utilized in North Dakota was the stripping shovel. Modern shovels are electric and have mechanical innovations to improve operating efficiency. A typical example is a variable pitch dipper which allows the cutting edge to maintain a proper angle as it moves through the overburden or coal. Shovels have been built as large as a 180 cubic yard capacity; however, they are limited by the weight of the "dipper stick" (see Figure 2b). This causes excess front end weight, limiting dipper capacity. The shovels have been retained in the strip mining process for coal loading because of their ability to dig consolidated substances easily. Stripping shovels must operate from the mine floor; therefore, they are subject to flooding or being buried by a collapse of the highwall. (Stefanko, 1973)

The dragline is the predominant stripping machine in North Dakota. Its design offers faster cycling and better maneuverability due to the reduced front end load (see Figure 2c). It can dig deeper than a stripping shovel and is suitable for operating from the highwall, thereby avoiding seepage and cave-in problems. It was thought the dragline could not handle denser overburden; however, larger buckets and longer booms offer improved cutting ability. The machine can effectively clean a coal seam and level its own spoil to provide a bench from which it may operate. Its effectiveness is somewhat reduced by freezing conditions as well as the fact that it requires considerable operator skill. (Stefanko, 1973)
Fig. 2. Stripping Equipment
Wheel excavators (Figure 2d) are the most efficient strippers in terms of weight and output. Continuous buckets strip at high output rates. The overburden is carried by conveyor to be evenly distributed along the spoil pile. This uniform spoil aids reclamation, and the conveyor provides low energy consumption. Wheel excavators have been used in North Dakota but were phased out due to reliability problems. (Stefanko, 1973)

The auger does not technically qualify as a stripping device (see Figure 2e). It is important in replacing underground drift mining and in cleaning additional coal from a mine no longer economical for stripping. The machine drills holes several feet in diameter into the coal seam for a depth of nearly 200 feet. This machine is not currently used in the State. The presence of an auger indicates that the mine is nearly exhausted.

Trends

Stripping machinery receives much attention since it accounts for 85 per cent of the energy expenditure in a surface mine. (Rumfelt, 1970) Increased coal demand and exhaustion of easily accessible coal seams have produced changes in machine scale. New mines require strippers to dig deeper, cast overburden further, and expose coal faster. Stripper capacities have evolved from fractions of a cubic yard to as great as 220 cubic yards. (Rumfelt, 1970) The largest stripping dragline in North Dakota has a sixty-five cubic yard bucket. Generally, the industry does not gravitate to the largest machinery. Mine economics and operating efficiencies are more important. A smaller machine with 80 per cent operating efficiency is likely to produce more than a
larger machine with 40 per cent efficiency. (Stefanko, 1973) If overburden thickness is somewhat uniform and demand is constant, older machinery may prove adequate. A telephone survey of all the mining companies in North Dakota revealed that the oldest stripping machine operating was thirty-five years old and the newest was nine years old. One long-time mine superintendent stated that, given proper maintenance and careful handling, a dragline can last indefinitely. Other mine personnel expressed the opinion that only a change in demand or acquisition of new mining leases create a need for different machinery.¹

New modes of surface mining have remained stable in recent years. However, techniques have changed. The utilization of a mixture of ammonium nitrate and fuel oil has replaced expensive dynamite for breaking up the coal seams. Drilling machinery has improved allowing deeper and larger blast holes to be used. Haulage machinery has enlarged and improved in the form of diesel/electric trucks.

Technological stability has allowed capital investment values to remain stable. Underground mining is plagued by costly specialized mining machines which have little value after they have been replaced by improved versions. Strip mining machinery is retained to augment new equipment or is sold to other mines. Ultimately, surface mining machinery becomes outdated. When replaced, particular attention is placed on operational reliability. (Christenson, ¹Telephone survey conducted by the author. The oldest stripping machine is operating at Baukol-Noonan's Noonan mine, and the newest is at Consolidation Coal Company's Glenharold mine.)
1962) The long-term trend is to use larger equipment with established performance records. This assures the ability to provide continuous production needed for mine-mouth power generation arrangements. (Stefanko, 1973)

Mine Economics

The reserve's geology, equipment capabilities, and production requirements determine the pit layout. It is arranged so as to minimize costs in the movement of earth. A coal mine actually consists of two earth-moving operations: the removal and side-casting of the overburden, and the removal and transportation of the coal. In an efficient mine containing a single coal seam, the overburden should be stripped and reclaimed to involve only one movement. Multiple seams require complex strategies for machinery with sometimes unavoidable spoil rehandling. Multiple rehandling slows the mining operation and adds to the coal cost. Computer simulation models show promise of optimizing mine movements. (Stefanko, 1973)

Coal movement is optimized by using larger haulage vehicles (up to 200 tons capacity) and ramps for dumping coal directly onto power plant conveyors. The fewer the links between source and destination, the lower the coal cost and more reliable the delivery. This is the virtue of a mine-mouth generation contract.

Two ratios are especially important to mining economics: the Blasting Ratio and the Stripping Ratio. Years ago, dynamite was used for breaking up overburden and coal. In 1956 blasting costs were as high as $.15 to $.20 per pound of explosive. The more recent use of ammonium nitrate and diesel fuel
has reduced costs to $.03-1/2 to $.07 per pound. (Stachura and Morrison, 1965)

A blasting ratio of seven pounds of explosive to one ton of coal represented a
high ratio if coal sold for $3 a ton at the mine. The blasting cost was thus a
significant portion of the price of coal. (Rumfelt, 1970)

The Stripping Ratio compares the amount of overburden that must be
moved with the thickness of coal recovered. The current maximum ratio may
be as high as twenty to one. This varies according to prevailing operating costs.
North Dakota ratios vary around ten to one, or thirty feet of overburden may be
removed to obtain three feet of coal.

Mine Layout

North Dakota mines usually follow a contour stripping pattern as opposed
to an area stripping pattern which is employed on flat land. (Greenberg, 1973)

In areas where topography causes overburden to exceed stripper capabilities or
the coal seam is inferior, box cuts are made until continuous stripping can
resume. (Van Sant, 1958) In North Dakota, coal seams generally lie horizontal
but are subject to undulations varying from one to twenty feet. Mining is
usually begun in a trough and progresses upward to allow drainage away from
the stripping or coal removal machinery. (Van Sant, 1958) Spoil removal is
confined to a movement of overburden from the highwall for deposit in a
previously mined area. This allows cuts to be progressively filled and leveled
for reclamation. Mines containing multiple seams of coal may require leveling
of the spoil pile to provide a working bench from which the stripper may operate
to remove successive layers of overburden. Machinery movement must be
minimized to conserve fuel and eliminate unproductive time. Efficient routing of haulage equipment insures continuous coal delivery to the power plant.

Close monitoring of mine geology, spoil movement, and machinery movement insures efficient and economical mine operation.

Two Typical Mines

This section describes two surface mines typical of coal mines operating in North Dakota. The first simulates a large coal mine which has a single thick coal seam. A mine of this type may produce one million tons of coal per year. The second example simulates a small mine with an annual output of 150,000 tons.

The large mine has relatively flat terrain with unconsolidated overburden. A dragline with a thirty cubic yard bucket is used to operate in an eight-to-one stripping ratio (removes eighty feet of overburden to reach ten feet of coal). The dragline begins operation by making a 120 foot wide cut the length of the pit to expose the coal seam (see Figure 3). A drilling crew drills a pattern of holes in the coal seam to allow blasting with ammonium nitrate and fuel oil. The broken coal is removed with a ten cubic yard loading shovel and transported by 150-ton capacity trucks to the processing plant. After the coal has been removed, the dragline makes successive cuts along the highwall to expose sixty feet of new coal. The spoil is deposited into the preceding cut. The newly exposed coal is blasted and removed as before. The dragline and loading shovel are electrically operated; the haulage vehicles are diesel/electric. As the mining progresses, the spoil pile is leveled by bulldozer and reclaimed.
Fig. 3. Views of a Dragline Removing Light Cover to Expose a Thick Coal Seam
The stripper operates twenty-four hours a day, 365 days per year, while loading and haulage operates twelve hours a day, five days per week.

The typical small mine does not have the benefit of a large stripping machine. It uses more economical standard earth-moving equipment because of cost and versatility. The operator uses six pan scrapers to remove a total of ninety feet of overburden from two coal seams as illustrated in Figure 4. The coal seams total thirteen feet to produce a stripping ratio of seven to one. Older scrapers must be push-assisted during digging with the aid of a bulldozer. Newer models of scrapers can push each other. Because the machines are capable of ripping hard overburden, blasting is unnecessary. Scrapers can carry from twenty-five to forty cubic yards of overburden depending on age and box modifications and can make a round trip from coal to spoil pile in three to five minutes. The total fleet can remove up to seventy cubic yards of overburden per minute. (Dragline cycle time averages sixty seconds; therefore, they move their bucket capacity per minute.) The exposed coal seam is blasted and removed by loading shovel. Haulage is accomplished by more conventional diesel dump trucks. Stripping is accomplished for six months, operating eighteen hours per day. This system is particularly noteworthy as reclamation is accomplished simultaneously with the stripping operation.

**Implications for Productivity**

Strip mined coal provides an option in the quest for inexpensive fuel. The process has displaced underground mining of general use coals for three
Fig. 4. Views of a Unique Multiple Seam Scraper Operation
principle reasons: economy, productivity, and safety. Advantages have caused
growth in the surface mining industry making it important for study.

Economics of strip mining come primarily because of high resource
recovery rates and the higher productivity of labor. Deep mining practices,
especially room and pillar extraction techniques, leave coal in the ground to
support the mine ceiling. The other method, longwall extraction, allows a
controlled roof collapse as the coal is removed. In either case, recovery is
quite low relative to surface mining, averaging around 60 per cent. If a seam
is thicker than eight feet, the excess coal must be left in the mine since
techniques are not available which safely support higher roofs. In contrast,
surface mining recovery rates approach 95 per cent because all of the
overburden is removed. The coal may be extracted without dangers of cave-in,
flooding, or gas.

Both processes are man controlled as opposed to machine controlled.
The greater the control by man, the greater the production variation. (Abruzzi,
1956) Strip mining has a low concentration of labor; therefore, labor costs are
less burdensome. Strip mining provides a more reliable supply of fuel for the
long-run demands inherent in power generation.

Productivity of labor has been higher in strip mines than in deep mines.
Labor productivity is generally measured in units of output per man per day.
(Salter, 1960) Table 2 shows the relative labor productivities of deep and
strip mining. Surface mining, being less labor intensive, has higher labor
productivity. Enlarged machinery creates more dramatic increases in surface
| Year | Deep Mines | | Strip Mines | | Per Cent of National Production |
|------|------------|----------------|----------------|--------------------------------|
|      | National Average Output/Man/Day | National Average Output/Man/Day | North Dakota Average Output/Man/Day | |
| 1945 | 5.04       | 15.46           | 19.06        | 19.0                  |
| 1950 | 5.75       | 15.66           | 27.45        | 23.9                  |
| 1955 | 8.28       | 21.12           | 35.90        | 24.8                  |
| 1960 | 10.64      | 22.93           | 37.07        | 29.5                  |
| 1965 | 14.00      | 31.98           | 45.90        | 32.3                  |
| 1970 | 13.75      | 35.96           | 76.49        | 40.5                  |
| 1971 | 12.03      | 36.26           | N/A<sup>a</sup> | N/A           |
| 1972 | 11.91      | 35.88           | 101.88       | N/A                  |
| 1973 | 11.66      | 36.33           | 102.36       | N/A                  |
| 1974 | 11.31      | 36.64           | 66.83<sup>b</sup> | 54.0                  |


<sup>a</sup>Data not available.

<sup>b</sup>This unexpected change in labor productivity was probably caused by the passage of a new comprehensive strip mine reclamation bill in 1973. The additional requirements for reclamation have the effect of displacing productive labor to non-productive tasks.
mining productivity, and the mine geology contains fewer work-stopping hazards. North Dakota productivity has been as high as 111.72 tons per man day. The national average was 35.96 tons per man day in 1970. This compares with 13.76 tons per man day for the same period in deep mines. (North Dakota Geological Survey, 1973)

The period from 1965 to 1974 demonstrates a change in productivity for both surface and deep mines. Productivity of surface mining may have increased because of shifting production from dangerous deep mining to safer surface mining. (Minerals Yearbook, 1965) Fabricant believes that since surface coal is less costly than other fuels, demand has prompted increased output and the employment of improved recovery techniques. This, in turn, results in higher labor productivity and further lowers unit costs. (1969)

Safety may be the greatest reason for the expansion of surface mining. Multifatality accidents are practically non-existent. S. Stradley promotes the notion that safety legislation has reduced productivity to safe output levels in underground mines. Table 3 demonstrates how extreme the difference in accident experience is between surface and underground mining. The safety problem may also work to support Fabricant's idea. Until deep mining becomes more automated, the process will continue to lag behind surface mining in labor productivity.

Conclusions

Lignite coal is low in heat value but burns cleanly. It is abundant in North Dakota with reserves covering the western third of the State. Soft
TABLE 3

INJURIES IN UNDERGROUND AND SURFACE MINES

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<td><strong>Number of injuries</strong></td>
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<tr>
<td>Total disabling injuries</td>
<td>10,425</td>
<td>1,246</td>
<td>9,235</td>
<td>1,153</td>
<td>6,737</td>
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<tr>
<td>Fatal</td>
<td>127</td>
<td>19</td>
<td>104</td>
<td>17</td>
<td>95</td>
<td>26</td>
<td>111</td>
<td>34</td>
<td>109</td>
<td>24</td>
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<tr>
<td>Nonfatal</td>
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<td>1,227</td>
<td>9,131</td>
<td>1,136</td>
<td>6,642</td>
<td>1,175</td>
<td>8,654</td>
<td>1,650</td>
<td>11,055</td>
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<td><strong>Frequency rates per million employee hours</strong></td>
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<tr>
<td>Total disabling injuries</td>
<td>55.88</td>
<td>24.03</td>
<td>49.20</td>
<td>20.18</td>
<td>35.32</td>
<td>16.48</td>
<td>37.59</td>
<td>17.49</td>
<td>45.70</td>
<td>18.50</td>
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<td>0.48</td>
<td>0.35</td>
<td>0.37</td>
<td>0.30</td>
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<tr>
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<td>16.13</td>
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<td>17.14</td>
<td>45.33</td>
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overburden characteristics allow easy recovery by strip mining techniques. The value of the reserve has been responsible for early growth in western North Dakota. Current development promises to provide important sources of electrical power and synthetic natural gas.

Surface coal mine planning begins with a thorough survey of the reserve geology. This information combined with market demands determines the type and scale of equipment used. Continual monitoring of production data and resource characteristics insure stable production of coal. Computer analysis has assisted in solving these problems.

Machinery size has increased to provide economies of scale, although machinery technology has remained somewhat stable in recent years. Blasting ratios and stripping ratios are important to maintaining an economical mine. Strip mining North Dakota coal is superior to deep mining because of economies inherent to extracting coal without severe domination by geological hazards.

Labor productivity is significantly higher than in the deep mining industry because of the higher degree of mechanization and the influences of safer working conditions. Legislative constraints on deep mine safety and domination of the coal market by strip mined coal contribute to the different levels of labor productivity found in comparing deep and surface mining.
CHAPTER III

LITERATURE REVIEW

Introduction

The previous chapter dealt with the lignite industry in its practicum. The relative ranking of coal was described as well as its general location in North Dakota geology. This was followed by a description of mining history and the mining process—how equipment is selected and how the mine is operated. It is apparent that the geological structure of the resource is a key determinant of the level of capital investment expended by the mining companies. It also is a key determinant of the rate of extraction (the productivity of the workers using the equipment).

This chapter contains three major investigations which progress from the theoretical to the practical. First, the apparent lack of concern for land based fixed factor production theory by economic theorists is discussed. The factors of production employed in the mining industry are evaluated according to their relative relationships in terms of production theory. Production theory is applied to explain the resource extraction process. Ricardian rent theory is examined as a basis for a theory of resource acquisition. Second, individual factors of production are presented as they apply to the mining environment. Each is explained in terms of resource allocation. Third, noteworthy studies
of the mining industry are presented with explanations of their findings and limitations as applied to the North Dakota lignite industry.

**The Mining Problem and Production Theory**

Mining economics is similar to agrarian economics. The factors of production are the same. Both are land based production processes. The land resource is a fixed resource. It determines mine productivity just as weather and soil fertility determine farm productivity. Capital is the investment made in the machinery which is used to extract the resource and transport it to market. Labor controls the operation of the machinery. Mining is a man-controlled production process as opposed to a machine-controlled production process; therefore, labor quality also affects productivity. A fixed proportion exists between capital and labor. This sort of economic theory is referred to as land based fixed factor production theory. Recent economic theorists have tended to be involved with variable factor production theory which applies to factory production, neglecting mining and agricultural production theory.

**Primary Resources and Production**

Before the industrial revolution, the physiocrats presented agriculture (and mining) as the only truly productive economic activity. Manufacturing was believed to be economically sterile because it only transforms, rather than creates, new wealth. (Oser, 1963) Of course, the "value added" concept was not being considered. Malthus, with his theory of population growth outstripping the food supply, and Ricardo, with his theory of differential rents
brought about by varying land quality, were the last major economists to incorporate land variables in their economic theories. The physiocratic influence disappeared in the early 1800's with the coming of the industrial revolution. At this point, the fascination with the power of the factory attracted the attention of economists more so than land. Therefore, until today, a theory consistent to mining and agricultural production is generally lacking. (Meier, 1970) Production theory must be used to analytically describe the mining cycle.

Production theory was slow to develop because of controversy about what production is and what productivity measures. The problem is simplified by defining productivity as two forms of measurement. The first is considered an input-output relationship, or the "total productivity" approach. This productivity measurement is the change in output resulting from a unit change of labor and capital combined. It not only measures labor volume and time but also measures capital investment. Capital investment can include intangible values of education and the tangible values of machinery investment. This measurement provides a weighted measure of productivity because labor input is differentiated according to its contribution to output and machinery input is differentiated in a similar manner. The resulting index describes the efficiency at which factors are being utilized. (Fabricant, 1969)

The second measure of productivity is labor productivity. This measure describes the level of output being produced or the fruitfulness of human labor under varying conditions. Labor productivity encompasses the efficiency aspect of total productivity, changes in the volume of tangible capital per man hour, and changes in the quality of labor. (Fabricant, 1969) Although more
information is contained in the "labor productivity" measurement, it is appropriate to use in this study because less specific data is required for its calculation. It also reflects changes in output caused by the other factor of production (land), as well as labor and capital. The complicating characteristics of this productivity measurement should be kept in mind as labor productivity data is evaluated in later chapters.

The Production Function

Production functions are classified into two general groups. The first group is the variable proportions production functions. This approach to production theory allows for a variety of combinations of the factors of production, especially labor and capital. This implies that a range (the economic region) of factor combinations exists that will produce a given output. Within this range, there is an infinite variety of labor-capital combinations. The rational owner is able to experiment with the factor proportions, making incremental adjustments, until that combination which minimizes costs is determined. This is an economic theory of production because the owner is responding to factor prices as the criterion for choosing a particular labor-capital mix.

However, if the owner is faced with a limited number of engineered factor combinations, these factor combinations being insensitive to short-run changes in factor prices, then a second group of production functions is appropriate. This is the class of fixed proportions production functions. In this class, an increase of one factor of production is a necessary but not a
sufficient condition for an increase in output. The combination of factors of production is implied to be a technologically engineered input-output ratio. The class of fixed proportion production functions is important to the mining industry since the factors of production are utilized in fixed combinations; that is, one bulldozer has one operator or a certain thickness of overburden requires the use of a specified combination of characteristics in the stripping machinery to be able to produce a given coal output.

To further illustrate the difference between the two classes of production, a quality of fixed proportion production functions called "limitationality" may be discussed. The concept of limitationality is present in two degrees, as illustrated by Figure 5. Figure 5a represents "complete limitationality" where there is no substitutability of factors once the scale of production has been chosen. (Georgescu-Roegen, 1966) In the actual mining environment, the geology of the reserve is assessed, and a specific combination of labor and capital is selected which will produce the required output. Among the mines, therefore, there is a range of outputs (line OM) where the combinations of fixed factors are limitational.

Within a mine, the "limitational law in a wide sense," illustrated by diagram 5b, is likely to apply. (Frisch, 1965) In a very narrow range, resources may be variable. This might be accomplished by momentary changes of labor allocation among machinery. The narrow area of variability occurs between production lines OM₀ and OM₁.
Fig. 5. Limitationality of Resource Combinations

This discussion is applicable to strip mining because a definite range of alternatives is apparent to the mining industry for the economical removal of overburden and coal. However, once the capital investment has been made in machinery, only one combination of factors is possible. The design of the selected machinery determines the amount of labor necessary for its operation. S. Stradley noted a similar situation in underground bituminous mining; only one person can operate a coal-cutting machine. (1977) Since the capital-labor combination is fixed, changes in labor productivity may be attributed to
resource changes or other external factors (company structure, specialized geological conditions, or safety problems).

Resource Extraction

One of the best measures of the rate of resource extraction is labor productivity. Tabular data presented in Chapter II indicates that labor productivity changes over time. The observable labor productivity data indicates change has taken place both in the short run, when no new equipment has been added to the production process, and in the long run, as mining companies acquire new equipment. Since the labor resource is fixed to the capital investment of equipment, variations in the rate of resource extraction must be explained by changes in the land or changes in the machinery investment.

Short-run changes in labor productivity are predominantly caused by variations in the reserve geology or incidental influences of changes in legislative requirements affecting mine operation and labor disturbances caused by strikes or work slow downs. Since incidental influences are unpredictable and extremely variable, they are disregarded. Reserve geology, then, is important in determining labor productivity in the short run. Figure 6 is useful in illustrating these fluctuations.

Assume labor, \( H_0 \), and capital, \( K_0 \), are combined in a fixed proportion to produce output \( Q_1 \). During this time period, \( t_1 \), mining progresses smoothly and production is at an optimum. Suppose that during a later period of time, \( t_2 \), mining becomes more difficult due to geological disturbances, such as
fault lines, rock lenses, or water seepage. As the mining machinery encounters these geological characteristics of the reserve, mining becomes less efficient causing the volume of extraction to drop to level $Q_2$. This implies a decrease in the average product of labor where a lower output is obtained for the same expense and less resource is extracted per unit of labor employed. (Stradley, 1977) The resource element, in this case land, causes undulations in the rate of extraction of the mine as measured by labor productivity. The ability to predict these disturbances is limited only by the extent which the reserve has been sampled by core drillings.

Reserve characteristics also can change the rate of extraction when viewed in the long run. The eventual exhaustion of the coal or the thickening of the overburden to the point where mining is uneconomical are two examples. However, the coal reserves are generally consistent throughout the lignite-
bearing strata of North Dakota geology. The nonavailability of coal leases, a legislative constraint on mining, is more likely to terminate access to resources. For this reason, natural changes in geology are not regarded as the major influence for labor productivity changes in the long run.

The more important long-run influence on average product of labor is change in technology. For strip mining, the most important source of technological change is in the stripping machinery. Remembering the machinery needed to match the reserve requirements and demand requirements is selected before the opening of the mine, the machinery purchased represents the best technology available. The resulting labor productivity is par with the industry. As new mines open in succeeding years, they too open with equipment representative of the best technology available. Eventually, the first mine is no longer using the best technology, and its labor productivity will not be competitive with newer mines; labor productivity has dropped relatively. This is the effect Salter calls the "theory of best technology." It is appropriate for explaining apparent long-run changes in the rate of resource extraction.

New equipment is not purchased by mining companies unless the demand for coal has changed or machinery becomes functionally obsolete. When equipment is replaced, labor productivity is likely to increase because a new opportunity to acquire the best technology is present. This is not always the case. If best technology advances faster than capital durability allows replacement to take place, a gap develops; and the industry cannot compete effectively in the market. (Salter, 1960) The result is an industry wide slowing
in the rate of increase or a decline in labor productivity. Increasing unit costs of labor and capital force higher product prices which also threatens market position. These effects are exemplified by the disparity between deep mining labor productivity and strip mine labor productivity in the market for general use coal.

Results of the changes in rates of extraction are important to mining companies. The trend in North Dakota has been for smaller companies to drop from the industry. As new stripping machinery is constructed, larger, more efficient models are being designed. Considering the possibility of a technological gap in the industry, strip mine labor productivity might be expected to stabilize. Long-term contracts afforded by mine-mouth power generation also stabilize the rate of extraction by fixing demand and eliminating open market competition.

**Ricardian Rent**

Mining is a land based production process. Land characteristics are the prime determinants of the fixed factor ratios (labor and capital) in the mining process. The importance of land quality in the mining process suggests the possibility of Ricardian rent. Traditionally, the Ricardian theory of differential rent is applied to agriculture where land parcels of varying fertility are farmed. The least fertile land is farmed using a fixed combination of labor and capital producing a yield of \( x \) bushels. A second parcel of land is farmed using the same fixed combination of labor and capital and bears a yield of \( x + 1 \) bushels. A third, and still better, parcel being farmed, again with the same
combination of labor and capital, yields $x + 2$ bushels. In this example, given a price that equals the cost of production on the first parcel, the first land produces no rent. However, the succeeding parcels of land produce rent amounting to one and two additional bushels. This effect is also present in coal mining. Ricardian rent is obtained by mining companies when they are able to mine reserves which contain thinner overburdens, thicker coal seams, or better quality coal.

The ability for mining companies to obtain Ricardian rents is determined by their ability to acquire better-than-average quality coal reserves. This process of reserve acquisition is termed "discriminative selection." (Christenson, 1962, p. 49) Once the reserves are obtained, they are consumed in order of decreasing fertility. C. Christenson argues the Ricardian theory of differential rent must be modified to the extent that the concept of "original and indestructible properties of land" is disregarded. Coal is a limited resource in that once extracted, the reserve is consumed. (Christenson, 1962, p. 49) The investigation of this theory is important to understanding the coal industry.

When determining the presence of Ricardian rent and discriminative selection of reserves, important factors include: recoverability of the resource, relationship between the reserve and the market, and company organization. C. Christenson and S. Stradley investigated the bituminous coal industry and have found a relationship between industry and the geology of the coal reserve. (1962, 1977) This relationship is indicated in surface mining.
Large companies develop long-term supply contracts with a co-locating coal consuming facility. Small companies ship their coal long distances to reach a market. These activities are summarized by "the size of a coal company is limited by the extent of its market, providing first that it has the good coal." (Christenson, 1962, p. 52)

Re-examination of Factors of Production in Terms of the Strip Extraction Techniques

The previous section presented particularly important production concepts as they apply to the mining industry. This section examines the analytical framework previously developed with respect to the peculiarities of strip extraction. The special characteristics of the factors of production employed in strip mining are examined in light of the mining cycle.

Land

Land varies in quality from one mine to another and is exploited according to principles of discriminative selection. Factors determining land quality are texture, moisture content, topography, characteristics of coal seams, and thickness of the overburden. The land qualities most easily quantified and of most importance to this investigation are seam thickness and overburden thickness.

Coal seam thickness represents resource abundance. It is reasonable to assume that companies which must fill large demands are inclined to select thicker coal seams according to the theory of discriminative selection. The more abundant the resource, the more favorable the stripping ratio becomes.
and the more economical the mining operation will be. Thicker coal seams, therefore, allow reserves with thick or difficult overburdens to be successfully mined.

Overburden thickness presents a physical rather than economic barrier to mining. Deep mining techniques penetrate the material covering the coal by way of tunneling; therefore, it has great flexibility in determining how deep the mining company should go to economically recover coal. Surface mining is limited by the capabilities of the machinery. Draglines can remove overburden to depths of approximately 120 feet thick. Other stripping machines are capable of less. Demand and coal seam fertility may create a need for building larger stripping machinery. This cost must be compared to projected revenues to determine if such development is profitable.

Capital

Capital represents the total financial outlay of the mining company. This outlay represents two forms of capital investment. The first form of investment will be called "the capital investment of extraction" and the second form will be "the capital investment of operation."

The capital investment of extraction is represented by extraction equipment, haulage equipment, as well as the amount for labor and raw materials. The primary determinant of this particular form of investment is the reserve geology with product demand, or required output, being the second determinant. The initial expenditure for this extraction investment must be suitable for the future geological reserve demands and future production
mands. To emphasize this, Salter quotes Professor Hicks saying, "an entrepreneur by investing in fixed capital equipment gives hostages to fortune. . . . long as the plant is in existence, the possibility of economizing by changing the method or scale of production is small; . . . ." (1960, p. 4) The extraction investment follows the guidelines of the predetermined production function, \( Q = \min \left[ \frac{H}{\alpha}, \frac{K}{\beta} \right] \), where the quantity produced determines a minimum outlay of the fixed factor combination of labor, H, and capital, K. (Stradley, 1977) The specific output is determined by demand, and the fixed factor combination is also determined by the reserve geology.

Different mining efficiencies are noted for similar companies, emphasizing the influence of reserve geology on the extraction investment. Figure 7 demonstrates the variations of the capital investments of extraction.

Fig. 7. Variations of Fixed Investments Among Producers

Line OA represents an investment suitable for the environment in which capital/labor combination \( Q_0 \) is used, and OB represents an investment, more labor intensive, in which \( Q_1 \) capital/labor investment is more suited. In practice,
the process of comparing capital investment of extraction between mining companies is difficult when different equipment and labor combinations are used. A productivity concept, which measures output per unit of time, is used in Chapter V to make this comparison. This is done to conform to the principle of productivity measurement discussed earlier.

The second form of capital investment, capital investment of operation, is the investment which creates the organizational form adopted by the mining company for operation and marketing. Investment of operation is important to this study because it relates the varying investments of extraction among companies to the variable quality of the resource. Thus, it will be used to indicate how Ricardian rents are captured, explaining the practice of discriminative selection of coal reserves. Because some reserves require a smaller investment of extraction to obtain a given output of coal, it is conceivable that companies will adopt their organizational form to obtain cost-saving coal reserves. C. Christenson and S. Stradley have attempted successfully to correlate investment for operation with reserve fertility. (1962, 1977) They have suggested that companies can be classified into four forms: integrated companies (mine coal for their own use), interstate companies (mine coal on contract in several states), intrastate companies (mine coal on contract in one state), and single companies (own and operate only one mine). Mining companies are fitted to these classifications and compared to coal reserve qualities or indexes of investment for extraction. Their results show that companies organize to maximize marketing and financial strength and are able
to capture Ricardian rents by selecting coal reserves that tend to allow the smallest extraction outlay for meeting required output. A similar test of the North Dakota coal companies is conducted in Chapter V of this study.

**Labor**

In the surface coal extraction industry, labor is fixed to the capital investment of extraction. The fixed proportion of extraction capital and labor is determined by the firm's extraction investment, this being influenced by demand and geological requirements. This proportion is, in turn, acted on by variations of the land resource. Our goal is to explain how this resource variation influences, in particular, labor productivity.

The most widely used measurement of labor productivity is termed the average physical product of labor. Within the setting of a single mine, labor productivity measures the efficiency by which the factors of production are utilized. When viewed over the short run, the measurement shows changes in production caused by variations in geological characteristics of the coal reserve. When labor productivity is compared among mining operations, it also provides insight into comparative operating efficiencies. More importantly, it can be used to discover differences in efficiency determined by the resource, and thus the presence of Ricardian rent.

The derivation of the average labor product is described by S. Stradley as a comparison of two combined resources—labor and capital. He starts with an efficient production set shown in Figure 8. Ray OS represents a single process
Fig. 8. Derivation of the Average Physical Product of Labor

which is demand oriented and geologically determined. \( Q_0 \) represents the
level of output obtained by the particular factor mix. Since the isoproduc
t line, \( Q_0 \), is represented by a right angle, it implies a fixed combination of
factors: capital, \( K \), and labor, \( H \). \( H_1 \) represents "labor required per shift."
Labor productivity, then, is conventionally represented as the quantity
produced per shift divided by the labor required per shift, or \( Q_0/H_1 \) (Stradley,
1977). The form used in this investigation uses the quantity of labor and output
on a per-day basis rather than a per-shift basis due to data limitations.

The Producers Production Set

The producers production set is the producers optimally efficient level
of production given specific combinations of labor and capital. This production
set is geologically determined and does not vary unless a different engineered
combination of labor and capital is adopted. In strip mining, this could involve
an extraction equipment modification as subtle as changing the boom length or
bucket size on a dragline to as radical as the purchase of an entirely different stripping machine. Observing a diagrammatic representation of the producers production set can clearly illustrate effects on output caused by a change in resource quality. Resource quality varies as mining and machinery moves through a given coal reserve because of changes in overburden thickness, coal seam thickness, water problems, or rock intrusions, to name a few. The diagrammatic representation of the producers production set can also illustrate the effects of the differential mining efficiencies among similar mining operations and the capture of Ricardian rents by companies operating in better-than-average quality reserves. Furthermore, the diagrammatic representation can illustrate differences in fixed proportion requirements of labor and capital between two different extraction techniques.

Figure 9 is a diagrammatic illustration of the producers production set. In the figure, a given extraction technique has been chosen for a certain coal reserve. That extraction technique implies an engineered combination, or a fixed proportion, of labor and capital ($H_1$ and $K_1$ are fixed at A). Under ideal conditions, the engineered combination of labor and capital will extract a given amount of coal. In the case of a stripping machine, a given quantity of overburden is removed (illustrated as distance $Q_1O$ as projected from $AB_0$). The resulting most efficient producers production set is represented by ray $OS_0$. (Stradley, 1977) Points below the ray, such as $B_1$ and $B_2$, indicate less than maximum utilization of the factors.
Fig. 9. Producers Production Set for a Given Extraction Technique

This optimally efficient production set may be equated in practice to the engineer’s calculated production capabilities of the equipment employed in the mine. When production actually proceeds, output is likely to be less than the calculated amount because of unexpected variations in reserve characteristics. In strip mining, this would primarily consist of changes in coal seam thickness and overburden thickness. As coal reserve characteristics continue to fluctuate during the mining process, the producers production set would also fluctuate by varying degrees below the optimally efficient production set (ray $OS_0$).

This illustrates the effects of variable on a fixed proportion of land and capital within a given coal reserve.

Differential mining efficiencies among similar mines can also be illustrated by Figure 9. The differential efficiencies are caused by the variable land factor of production. This gives rise to the capture of Ricardian rent by mining companies operating in better-than-marginal quality reserves. Suppose
three mining companies have similar coal reserves and identical technologies are used in removing overburden and extracting coal. The fixed factor proportions of labor and capital would be identical. All three mines would have the same optimally efficient production set as represented by ray OS₀. Assume that the three mines operate in different quality reserves (overburden, seam thickness). Variations in reserve characteristics cause mining company number one to conform to ray OS₀, company two to conform to ray OS₁, and company three to conform to ray OS₂. The differential mining efficiencies are apparent from the different producers production set each mining company achieves. All three unique production sets are a result of variable resource conditions.

Further suppose the price of coal is determined by the production set OS₂ and company three is able to recover mining costs to maintain a profitable market position. Providing the average total cost curves of the second and first mining companies are less than company three and equal to or greater than that afforded by the optimally efficient producers production set, they will capture Ricardian rents. Company two captures rent equal to distance B₁B₂, and company one captures rent equal to distance B₀B₂. Again, their advantageous market positions are a result of variable resource conditions.

Finally, Figure 10 represents the producers production set of two different extraction techniques which are theoretically capable of producing equal outputs. Let ray OS₀ represent the optimal producers production set of a dragline. This ray is derived from the geologically engineered combination
Fig. 10. Producers Production for Different Extraction Techniques

of the fixed production factors labor and capital (H₀K₀ fixed at A₀). The second ray (OS₁) is derived from the combination of fixed production factors of land and capital (H₁K₁ fixed at A₁) associated with the optimal producers production set of a pan scraper stripping system. The pan scraper extraction technique is observed to be less capital and more labor intensive than the dragline. Small mining companies are attracted to this technique because of the lower cost of equipment and flexibility available in the high labor concentration. It is apparent from this illustration that each variation of technology will change the producers production set. This presents an infinite range of variability caused by changing land characteristics when one views the coal extraction process industry wide. The actual determination of differential mining efficiencies and Ricardian rent is technically a near impossible task.
Supporting Literature

Several studies have been made to determine relationships of factors of production to the productivity of labor in the bituminous coal industry. They provided the basis for this inquiry of the North Dakota lignite industry.

The earliest is that of Hubert E. Risser studying the changes of the coal industry of the United States from 1903 to 1953. Using representative tabular data, he follows the evolution of key relationships in mining during the period. Comparing strip mining and deep mining, he noted strip mining has higher productivity. Comparing seam thickness to average productivity of labor, he states that thicker seams also have higher productivity. Risser notes an important trend in increasing productivity and attributes it to improved mechanization. Tabular data agrees as more automated devices are instituted, productivity increases. A key point of this study is the use of average productivity of labor as an index for comparing industry growth and change. The measure exposes the advantage of strip mining over deep and leads Risser to predict technology will allow deep mining to close the gap and deeper overburdens will decrease strip mine productivity.

Risser also conducted an investigation into productivity and its relationship to company size. He determines thick seams can be exploited easier by large companies than by small companies and comments on the economic rents incurred. Financial strength is credited for this action. Data presented also reveals higher labor productivity for larger companies than smaller companies and attributes this to the higher level of mechanization found in larger
companies. It is important to note that his measure of company size is mine output. An interesting presentation shows similar-sized mines in different states have different labor productivities. He feels this is due to different geological characteristics of the reserves.

Risser's conclusions predict some current trends. He predicts coal will be of increasing importance for power generation and decreasing importance in heating and other markets as it is replaced by oil and gas. The importance of technology in the productivity of mining is emphasized, and he notes the increase would slow as safety limits are reached. He predicts extensive development of lignite stripping. Finally, he predicts competing energy sources will not long displace coal as their depletion will require development of the coal industry to fill demand. (Risser, 1958)

A second important study was done by C. L. Christenson. His study focuses on the changes of the coal industry from 1930 to 1960. He investigates the effects of company size on production also, but uses a scheme taken from The Keystone Coal Buyers Manual. This system classifies companies into four types: integrated, interstate, intrastate, and single. He finds large companies tend to operate large mines (which could explain H. Risser's success) and control a larger share of the coal market.

Christenson investigates the relationship of company size and resource quality and concludes that, in accordance with the theory of discriminative selection, the thicker coal seams tend to attract large companies. Furthermore, he observes a dual selection where the companies first select
the best quality coal, then seek the thicker seams. Smaller companies only obtain second-rated reserves. He observes that these trends vary between states and are weaker in the surface mining industry.

Furthering his investigation, Christenson observes data of output and daily productivity. Despite data problems, he found indications that mines with high daily production parallel with those mines which work the most days per year. These, in turn, are associated with integrated and interstate companies. Christenson explains that larger companies tend to have long-term, high-demand commitments. This realignment of consumption forces a higher technology. Cost advantages and advantages of higher output capabilities are giving surface mining a greater share of the market. Underground mining must change technology to compete and consequently is at a disadvantage. (Christenson, 1962)

A third study investigating implications of productivity and coal extraction was done in 1977 by S. A. Stradley. The study directly addresses the underground bituminous coal industry of Utah. The bituminous industry is thoroughly described in terms of productivity theory and arrives at similar conclusions to the preceding two studies. He finds a good correlation between seam thickness and productivity of the deep mine.

To study relationships of company size to resource characteristics, he uses the four-group classification scheme. In Utah, there is a weak association between average product of labor and company type. He did find somewhat stronger correlations between company size and seam thickness. Stradley's
study shows a strong relationship between coal quality and company type which again supports the theory of discriminating selection.

One area which differs from the preceding investigations is the consideration of mine safety and its effect on labor productivity. Stradley presents a strong argument for the use of legislation to reduce mine hazards and allow productivity to remain at the best-safe level for the workers. It is hoped that improved underground mining technology will be used for improving labor productivity as well as presenting a safer environment in which the miners are to work.

Limitations of the Literature

The current literature is generally lacking in coverage of the lignite surface mining industry. Rapid growth in the North Dakota lignite industry warrants a similar consideration. Surface mining trends pointed out by H. Risser and C. Christenson apply to bituminous coal and are dated by the chronological time in which they were made. The surface mining industry has grown tremendously. In 1955, strip mining controlled only 25 per cent of the industry market; however, by 1973, it controlled well over 50 per cent of the market (see Table 2 in Chapter II). Rapid growth, realignment of consumption patterns, and improved technology change relationships among the factors of production. Market changes affect company organization and legislative requirements. Existing studies may be adequate for bituminous mining; however, the study of the lignite industry will lay a groundwork for predicting regional impact and legislative needs for North Dakota.
Conclusion

This chapter contains three major investigations which deal with the fixed factor production theory associated with mining economics. Particularly important is the exogenous influence of variable land on the engineered combination of capital and labor. The results produce differential production efficiencies in mine production as represented by labor productivity changes. Among mining companies, opportunities are created for the capturing of Ricardian rents. Although several studies have been conducted into these concepts as they are found in a mining environment, the problem of strip mining is generally neglected.

The first major investigation begins with a discussion of the general historical development of land based fixed factor production theory. Study in this area has been neglected. The two concepts of productivity measurement are discussed with labor productivity concluded to being the best measurement for use in this study. The concept of limitationality is presented next so as to differentiate between fixed factor production theory and variable factor production theory. Strip mining production theory is concluded to fall into the category of fixed factor production.

The first investigation continues with a description of the causes of short- and long-run changes in labor productivity. Short-run changes are concluded to be caused by variable land influences and long-run changes result from technological changes. Productivity changes are used to explain changes in coal marketing and the decline of companies unable to adopt technological
change. The investigation concludes with a discussion of Ricardian rents. Differential production efficiencies afforded by variable land is described as the motive for discriminative selection of coal reserves by mining companies. The result of this action is the capturing of Ricardian rents.

The second major investigation examines the three factors of production in view of fixed production theory and the mining cycle. Land is described as having two main characteristics: coal seam thickness and overburden thickness. Coal thickness is important to the value of the reserve where overburden thickness is a barrier to mining.

Capital is divided into extraction capital and operational capital. Extraction capital is a fixed factor combination with labor with production efficiency influenced by variable land. The resulting differential affects operational capital where specific organization or marketing configurations are adopted by mining companies. These arrangements enable the capturing of economic rent.

Labor provides an easily calculated measure of production. Labor productivity is derived by dividing a given production quantity by the amount of labor needed for its production.

The second investigation is concluded by a diagrammatic presentation of the producers production set. This discussion summarizes the importance of variable land towards the fixed proportion of labor and capital. Differential production efficiencies are visualized, and Ricardian rent is illustrated. Finally, effects of different technologies on production factor combinations are presented.
The last major investigation considers three major studies in mining economics. Although all three are strong in their evaluation of deep mining, strip mining is found to be insufficiently covered. The following chapters of this study attempt to fill this void.
CHAPTER IV

THE RESEARCH MODEL

Introduction

This chapter is an outline of factor relationships which are tested in Chapter V. It also presents the statistical methods which are used to test the relationships and special problems encountered in the testing. Relationships presented are: natural resource effects on labor productivity, technological effects on labor productivity, and industry organizational relationships toward the factors of production. In basic terms, this is a study of the interrelation of land, labor, and capital and their ability to predict one another. This chapter contains detailed explanations of the variables used for the statistical tests in Chapter V.

Resource Characteristics and Labor Productivity

The preceding chapter discusses the influence of resource characteristics on mining practice. It is difficult to quantify the effects of characteristics such as water seepage, sandstone lenses, or clay intrusions on mine production. Consequently, these factors are ignored, and attention is focused on quantifiable resource characteristics. In surface mining, these are coal seam thickness and overburden thickness. Assuming the imperfections are distributed uniformly
throughout all mines, coal seam thickness and overburden thickness represent relatively reliable data for comparison with labor productivity by mine.

**Coal Seam and Average Product of Labor**

Results of bituminous industry studies confirm what the coal industry assumes is fact. That is, within limits, as the coal seam becomes thicker, the average productivity of labor increases. This direct relationship is also hypothesized in this paper. To illustrate this concept, assume an equal amount of overburden must be removed to reach the coal seams of two mines. The coal seam in one mine is ten feet thick and, in a second mine, is twenty feet thick. With the same manpower, equipment, and time period employed in both mines to remove the overburden, a greater amount of coal is exposed in the second mine. Uncovering the coal is considered to be the majority of the mining effort since coal removal is an extremely efficient operation. Labor energy expended is nearly the same in both mines; therefore, the mine containing the thickest coal seam seemingly has conditions which allow high labor productivity. This relationship is tested in Chapter V by extracting an average productivity of labor value for each mine in North Dakota and comparing it to the reported coal seam thickness of each mine.

Certain difficulties are encountered with this statistical comparison. C. L. Christenson presents national data indicating average coal seam thicknesses are decreasing over the years. (1962) Tables displayed in Chapter II of this paper indicate a general rise in surface mine productivity is occurring over recent years. Both of these facts contradict the hypothesis
that seam thickness is directly related to labor productivity. The difference between long-run and short-run analysis is important. Long-run analysis reflects improved technology and varying scales of production. Short-run analysis does not.

Another difficulty present is the problem of how to deal with split coal seams. One mine has forty feet of overburden which must be removed to reach a ten-foot coal seam. A second mine contains twenty feet of overburden to be removed to reach a four-foot-thick coal seam. Miners then must remove another twenty feet of overburden to reach a second coal seam six feet thick. The stripping ratios are identical in both mines; however, the machinery in the second mine must perform two stripping runs. This increases movement time and possible preparation of the path the stripping shovel follows. The lengthening of the time period, an element in productivity measurement, changes the resulting average labor productivity.

Without mentioning data inadequacies, the definition of labor productivity contains inherent inaccuracies. The most commonly used definition is output per man per day. Output is accurately verified by observing haulage records. Man data requires definition and two viewpoints exist. First, only the labor actually performing earth-moving tasks are regarded as miners and included in statistical tables. Secondly, maintenance, planning, and administrative personnel are also regarded as miners since they hold positions necessary for the mining operation. Assuming mining companies are cost minimizers, they employ the most efficient combination of labor. The definition of a work day
varies among mines. Some companies operate on as many as three shifts per day. Length of shifts varies. Travel time to and from equipment is non-productive and is included in shift time. In recent years, union activities are standardizing these variables. Finally, a productive day must be defined. Stripping machinery often operates twenty-four hours per day, 365 days per year, and coal recovery may take place two shifts per day, five days per week. Production data often reflects only coal recovery days.

Overburden and Average Physical Product of Labor

Underground mining techniques present dangers and difficulties in the form of roof control during the extraction process. Surface mining is safer, yet difficulties are present in a different medium. The overburden to be removed may be of heterogeneous texture and consolidation. The overburden thickness changes throughout the reserve due to surface topography and seam elevation. Changes in overburden characteristics are expected to change the productivity of the mine.

Overburden characteristics have been presented as important to initial equipment selection. If the overburden is unconsolidated and thick, the dragline is appropriate. If the overburden is rocky and difficult to remove, the leverage of a stripping shovel is important. Once the equipment is in use, the nature of the overburden continues to affect mine productivity. As in the consideration of seam thickness, assume two mines have equal coal seam configurations, single seams of equal thickness. The first mine has twenty feet of overburden, and the second mine has forty feet of overburden overlying the coal. Assume also
similar equipment, labor, and time period is used in both mines. The company
operating the first mine must remove only half the overburden which the second
mining company must remove to reach equal amounts of coal. Therefore, the
first company has a higher productivity than the second since its thickness of
overburden is removed in less time. Extending this illustration to a single
mine where the stripping machine is progressing from thin overburden in a
valley to the thicker overburden of a hill, the stripping rate would decrease as
the stripping ratio increases. Productivity also decreases. This variation in
productivity can be reduced through the use of contour stripping techniques;
however, thicker overburden must eventually be removed as the mining
operation progresses through the reserve.

Minor productivity fluctuations are also evident with the occurrence of
rock intrusions or water seepage. Since core drillings provide information
concerning reserve geology, these imperfections are predictable. Changes in
overburden thickness remain an important factor in explaining variations of
labor productivity. The hypothesis tested is that an inverse relationship exists
between overburden thickness and labor productivity. The reported average
labor productivity data for mining companies in North Dakota is statistically
compared to the overburden thickness of the mines in which they operate.

Natural and political problems are inherent to testing this relationship.
Water seepage and topography represent natural hindrances to mining. Water
does not present a serious problem in North Dakota except in a few mines
which have previously closed due to inefficient overburden ratios. Sumps dug
into the floor of the mine assists in collecting the water so it may be removed by pumps. Topography in North Dakota causes overburden thickness to vary from twenty feet to 120 feet, the limit of stripping machine capability to remove soil. Contour mining practices and sufficient minable land reduces this fluctuation.

Legislative requirements of reclamation have produced the introduction of a segmented stripping procedure. The first few feet of earth, which is biologically classified as topsoil, must be removed prior to overburden removal. Small uncut pillars are left standing for verification that this procedure has been done. Once approved by state officials, stripping continues. Following the removal of coal, the spoil is leveled and the topsoil is replaced. This additional procedure slows stripping and affects productivity. Since it is required of all North Dakota mining companies, the comparative influence should be minimal.

**Industrial Characteristics and Labor Productivity**

The capital resources of a mining company fall into two major categories: investment for extraction and investment for operation. Investment for extraction is represented by the investment made in machinery used to remove the overburden and the coal. Since the coal extraction equipment is less critical to the over-all mine productivity, only the stripping machinery is considered. Investment for operation is the form of organization the mining company has adopted for certain financial, administrative, or corporate
reasons. Both forms of capital investment appear to have effects on the average physical product of labor.

Equipment and the Average Physical Product of Labor

The trend for increasing machine size is noted in Chapter II. This increase comes because of pressure from changing conditions and from changing demand for coal. In accordance with the theory of discriminative selection of coal reserves, the coal industry recognizes that the availability of easily mined reserves is diminishing. Thicker overburdens and less easily penetrated soils are being removed. This requires stronger, larger stripping machinery. Improved machinery, in turn, represents greater capital investments by the mining companies. Trends toward mine-mouth power generation operations realign demand for coal. The demands are greater and of longer term. As mining companies shift from open market sales to long-term contracts, they encounter preserves to increase the scale of their stripping machinery. High demands from the power generation facilities can only be met with high output stripping machinery. It is hypothesized that this trend for larger machinery investment results in greater mining efficiencies and, consequently, contributes to higher labor productivity. Knowing the relationship proposed can assist in forecasting labor demands based on knowledge of demand and geology. The statistical problem is to accurately index machine size so as to reflect its investment value and compare it, using linear regression techniques, to calculate average labor productivity data.
The statistical problem involves indexing the stripping machinery. Several methods exist. The first to be considered is the Maximum Utility Factor method. This method attempts to measure the ability of a machine to do work and only applies to stripping shovels and draglines. The difference between the maximum and minimum effective operating reach is multiplied by the bucket capacity resulting in an index. This index is used to compare machines. The second method considered is called the Buckingham method. It multiplies machine costs, machine efficiencies, and opinion factors. The product is divided by designated standard opinion factors. This method is flexible but produces large variations in indexes. A third method, Gartners Index, tries to measure economic efficiencies. It divides machine service weight by the product of bucket capacity and cutting height capabilities. This index favors the mechanically unreliable and lightweight bucket wheel stripper. (Stefanko, 1973)

The system used in this paper is similar to labor productivity measurement. The measure is one which calculates the amount of earth moved per unit of time. This index allows the comparison of dissimilar equipment types such as draglines and pan scrapers. The entire stripping system is calculated as one unit as in the case of a miner who uses six pan scrapers to perform the stripping operation. This company's stripping index is higher than a company using a single dragline. The actual index is expressed as cubic yards of earth moved per machine operating hour.
The Statistical Test

In testing coal seam thickness, overburden thickness, and machine investment effects on labor productivity, similar procedures are used. The variables are compared using simple linear regression techniques. A "best fit" regression line is produced showing how much a change in the independent variable will change the dependent variable. $R^2$ shows how much of the variation in the dependent variable is explained by the independent variable. The student's t test explains the probability of the two variables being associated. These results are given in Chapter V.

Company Organization and Average Physical Product of Labor

The second hypothesis of capital resource is that a direct relationship exists between investment for operation and labor productivity. Studies of the bituminous coal industry note that as mining companies increase in size, their average productivity of labor does as well. (Risser, 1958; Christenson, 1962; Stradley, 1977) The question is if the North Dakota lignite industry follows suit. If this hypothesis is verified, further studies will project productivity or labor requirements based on mining company organization.

The data used for the statistical comparison are the North Dakota mining companies as they are classified in the four-type system and their respective labor productivity figures.

The special problem involved is determining what represents company size. H. Risser defines size as mine output (1953) C. Christenson and S. Stradley use a classification system from the Keystone Coal Buyers
This system ranks companies into four basic categories based on market type since it is observed that large companies do not necessarily have high output mines. This last system is used in Chapter V to provide continuity to the most recent studies.

Company Size and the Industry

A final set of comparisons provide continuity of ideas from previous studies in bituminous coal mining to North Dakota surface lignite mining. Concern is expressed by S. Stradley over the probability of large companies deriving differential rents due to mining better-than-average coal reserves. This idea of discriminative selection has important implications for North Dakota as well. In recent years there has been a rapid decline in the number of small family mines. This represents a shift in consumption patterns, as mine-mouth power generation facilities and projected coal gasification plants present demands for coal that the small operator is not financially able to fill.

Geological characteristics can be investigated by using overburden and coal seam data, comparing them to the four-level company classification scheme. This comparison determines if large companies have thicker coal seams or thinner overburdens.

The comparison of machinery productivity to company size provides insight into the extraction or machinery investment. If larger companies operate larger machinery, the relationship reinforces the notion that large size produces high labor productivity. Also, labor predictions can be made based on demand and geological information.
The hypothesis for these tests is that larger companies draw economic profits. This is due to their ability to use financial strength in acquiring favorable resources and extended supply commitments which result in greater investments as so indexed. Thicker coal seams and thinner overburden provide high productivity. The financial strength allows greater versatility in obtaining appropriately scaled stripping equipment. Co-location eliminates expensive coal shipment thereby minimizing consumer costs. A business arrangement such as this contains such cost-saving advantages that small producers have little hope to compete. They are driven from the market or forced to specialize in noncompeting segments of the industry.

The Statistical Tests

The investigations involving company-type comparisons employ chi square statistical tests for association. The variables are observed in the tabular form. The calculated chi square statistic is then presented as indicating the level of probability that a relationship exists between the two variables. Cramer's V statistic is also calculated to provide further information about an existence of a relationship. From these data, conclusions are made concerning the economic position of the mining companies.

Conclusions

This chapter presents the relationships and hypotheses which are tested in Chapter V. It also presents problems encountered in making the comparisons
as well as the methods used. The relationships presented provide insight into North Dakota lignite mining and a comparison to bituminous coal industry studies. In the chapter, average productivity of labor is compared with geological qualities of the reserve and the industry investments in machinery and operations. Industry characteristics are compared to reserve qualities to provide a full circle investigation of the primary factors of production. From these comparisons, ideas concerning labor requirement prediction based on geological and market information may be expanded. Knowing these relationships allows government to assess regional impacts of proposed mining activities.
CHAPTER V

FINDINGS

Introduction

This chapter contains the statistical results of the relationships described in Chapter IV. The analysis presented indicates the interrelatedness of the factors of production for the North Dakota lignite mining industry. Generally, the relationships being tested are: how the average physical product of labor is affected by variations in reserve geology and capital investment of the mining companies and an investigation into the presence of economic rents taken by mining companies. Implications of the statistical results include the ability to predict regional and economic impacts based on information concerning mine geology, product demand, and marketing structure of the mining company. This knowledge is of importance to government for planning legislation based on industrial growth and social impact.

Statistical Qualification

The statistical results presented in this chapter must be qualified. The production data being used is computed from data reported in the North Dakota Coal Mine Inspection Department Reports and, therefore, represent a continuous rate of extraction. The data does not reflect individual variations
of geological structure and topography which produce changes in labor productivity. In one case, exact operation data cannot be obtained from the State or mine, so estimated proxy information is substituted based on the experience of other mine operations. Resource data is obtained from the North Dakota Geological Survey and the mines themselves. The Survey data represent random core drillings made in close proximity to existing mines. Information from the mines concerning overburden is expressed as maximum and minimum thicknesses. The calculated averages do not accurately represent daily or weekly conditions. Seam thickness tends to be uniform throughout the State. The generalized data does not reflect intrusions, faults, or lensatic taperings of the resource edge.

A second point of consideration is that the data being used represents a census of the mines operating in a particular geological formation. The political boundaries of the State of North Dakota form the census limits. This data is not a random sample for the State; however, it may be assumed a sample of convenience for inferences made about the lignite industry of the United States. As a census of the North Dakota mining industry, this data allows stronger statements to be made concerning the interrelatedness of the factors of production.

Results: Factors of Production (Regression Analysis)

The results of this section indicate the interrelatedness of the factors of production in North Dakota lignite mining and tests the hypothesized relationships of industry structure as they apply to the theory of discriminative selection.
Coal Seam Thickness and Average Physical Product of Labor

Table 4 presents the tabulated data and results of the regression of coal seam thickness on the average product of labor. Little information concerning the relationship is readily observable from the tabulated data; however, investigating the variables using statistical analysis makes the relationship clearer. The regression equation indicates a one-foot increase in seam thickness results in a 0.73 ton per man per day increase in labor productivity. On the basis of this regression equation, a weak relationship exists between the two variables. The $r^2$ statistic verifies this by indicating that 1 per cent of the total variation of labor productivity is explained by coal seam thickness. Ninety-nine per cent of the variation in labor productivity is explained by other factors. The probability that a direct relationship exists, as indicated by $t$, is 63 per cent. Seam thickness, therefore, is not a strong predictor of labor productivity, although it does seem to be, especially when considered with the other criterion.

Overburden Thickness and the Average Physical Product of Labor

Comparing overburden thickness and labor productivity presents a special problem because of the apparent influence of a third factor. Table 5 displays the data and results of the statistical tests for interrelatedness. The regression line indicates that for every one-foot increase in overburden thickness, there is a 0.17 ton per man per day increase in labor productivity. Although the regression indicates a low factorial relationship, the $r^2$ statistic indicates a
# TABLE 4

REGRESSION OF COAL SEAM THICKNESS ON AVERAGE PHYSICAL PRODUCT OF LABOR FOR CURRENTLY OPERATING NORTH DAKOTA SURFACE COAL MINING COMPANIES, 1955 TO 1975

<table>
<thead>
<tr>
<th>Company Number</th>
<th>Average Product (Tons/Man/Day)</th>
<th>Average Seam Thickness (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>151.0</td>
<td>11.0</td>
</tr>
<tr>
<td>2</td>
<td>32.7</td>
<td>9.0</td>
</tr>
<tr>
<td>3</td>
<td>112.8</td>
<td>12.0</td>
</tr>
<tr>
<td>4</td>
<td>57.1</td>
<td>14.0</td>
</tr>
<tr>
<td>5</td>
<td>9.8</td>
<td>10.0</td>
</tr>
<tr>
<td>6</td>
<td>30.4</td>
<td>6.5</td>
</tr>
<tr>
<td>7</td>
<td>58.6</td>
<td>10.0</td>
</tr>
<tr>
<td>8</td>
<td>53.8</td>
<td>23.0</td>
</tr>
<tr>
<td>9</td>
<td>55.9</td>
<td>27.5</td>
</tr>
<tr>
<td>10</td>
<td>54.8</td>
<td>9.5</td>
</tr>
<tr>
<td>11</td>
<td>13.0</td>
<td>11.0</td>
</tr>
<tr>
<td>12</td>
<td>17.4</td>
<td>10.5</td>
</tr>
</tbody>
</table>

**Results**

\[
Y = 44.60 + 0.73X \\
\text{Dependent variable: output per man day} \\
\text{Independent variable: average seam thickness} \\
\]

\[
r = 0.11 \\
r^2 = 0.01 \\
t = 0.34 \\
S_{Y \cdot X} = 42.4
\]

### TABLE 5
REGRESSION OF OVERBURDEN THICKNESS ON AVERAGE PHYSICAL PRODUCT OF LABOR FOR CURRENTLY OPERATING NORTH DAKOTA SURFACE COAL MINING COMPANIES, 1955 TO 1975

<table>
<thead>
<tr>
<th>Company Number</th>
<th>Average Product (Tons/Man/Day)</th>
<th>Average Overburden Thickness (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>151.0</td>
<td>65</td>
</tr>
<tr>
<td>2</td>
<td>32.7</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>112.8</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>57.1</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>9.8</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>30.4</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>58.6</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>53.8</td>
<td>55</td>
</tr>
<tr>
<td>9</td>
<td>55.9</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>54.8</td>
<td>60</td>
</tr>
<tr>
<td>11</td>
<td>13.0</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>17.4</td>
<td>N/A&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Results

\[ Y = 47.78 + 0.17X \]

- **Dependent variable**: output per man day
- **Independent variable**: average overburden thickness

\[ r = 0.77 \]
\[ r^2 = 0.59 \]
\[ t = 3.59 \]

SY · X = 28.3

**SOURCE:** Average product is from North Dakota Coal Mine Inspection Department annual reports, 1955-1975.

<sup>a</sup>Not available.
moderate relationship exists. The $r^2$ statistic shows that almost 60 per cent of the variation in labor productivity is explained by overburden thickness, and 40 per cent of the variation is explained by other factors. The probability that this direct relationship exists, as indicated by $t$, is well over 95 per cent. These results are contrary to the hypothesized relationship and effectively indicate that as overburden becomes thicker, productivity increases.

**Stripping Machine Productivity and the Average Physical Product of Labor**

The stripping machine productivity is important in explaining the preceding relationship as it possesses a quality that may be associated to both factors. Machine scale is geologically determined in practice, and the stripping machine is essential to high productivity. Regression analysis demonstrates a moderate relationship exists between machine productivity and labor productivity (see Table 6). The regression line indicates a one cubic yard per hour increase in machine capacity produces a 0.01 ton increase in the amount of coal produced per man per day. The $r^2$ statistic indicates that 11 per cent of the variation in labor productivity is explained by stripping machine efficiency with 39 per cent of the variation explained by other factors. The probability that this direct relationship exists, as indicated by $t$, is almost 83 per cent.

**Overburden Thickness and Stripping Machine Productivity**

A regression of overburden thickness on stripping machine productivity is performed to complete the investigation of the three-way relationship which
### TABLE 6

REGRESSION OF STRIPPING MACHINE EARTH-MOVING CAPACITY ON AVERAGE PHYSICAL PRODUCT OF LABOR FOR CURRENTLY OPERATING NORTH DAKOTA SURFACE COAL MINING COMPANIES, 1955 TO 1975

<table>
<thead>
<tr>
<th>Company Number</th>
<th>Average Product (Tons/Man/Day)</th>
<th>Machine Capacity (Cubic Yards Per Hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>151.0</td>
<td>1,212</td>
</tr>
<tr>
<td>2</td>
<td>32.7</td>
<td>420</td>
</tr>
<tr>
<td>3</td>
<td>112.8</td>
<td>3,283</td>
</tr>
<tr>
<td>4</td>
<td>57.1</td>
<td>717</td>
</tr>
<tr>
<td>5</td>
<td>9.8</td>
<td>1,800</td>
</tr>
<tr>
<td>6</td>
<td>30.4</td>
<td>540</td>
</tr>
<tr>
<td>7</td>
<td>58.6</td>
<td>4,200</td>
</tr>
<tr>
<td>8</td>
<td>53.8</td>
<td>1,489</td>
</tr>
<tr>
<td>9</td>
<td>55.9</td>
<td>1,785</td>
</tr>
<tr>
<td>10</td>
<td>54.8</td>
<td>1,038</td>
</tr>
<tr>
<td>11</td>
<td>13.0</td>
<td>250</td>
</tr>
<tr>
<td>12</td>
<td>17.4</td>
<td>N/Aa</td>
</tr>
</tbody>
</table>

**Results**

\[
Y = 40.25 + 0.01X
\]

Dependent variable: output per man day

Independent variable: machine capacity

\[r^2 = 0.33\]

\[r^2 = 0.11\]

\[t = 1.04\]

\[S_{YX} = 41.54\]

**SOURCE:** Average product data is from North Dakota Coal Mine Inspection Department annual reports, 1955-1975; machine data is from coal companies.

*aNot available.*
exists among overburden thickness, machine productivity, and labor productivity. Table 7 lists the data and statistical results. The regression line equation indicates that a one-foot increase in overburden thickness results in a twenty cubic yard per hour increase in stripping machine productivity. This relationship means that upon the initial reserve assessment, the machinery selected will match the overburden thickness according to the ratio of the regression line. The $r^2$ statistic indicates that a fairly strong relationship exists as overburden thickness accounts for about 13 per cent of the variation in machine productivity. The probability that a direct relationship exists, as indicated by $t$, is about 85 per cent.

If one pair of data is removed from the table and statistical analysis redone, the picture is improved. The data removed is that of a single mine operation which employs a high labor stripping operation. The machine productivity of that mine can be considered unusual. The resulting regression line is basically unchanged; however, the $r^2$ and $t$ statistics rise. The new equation explains that 28 per cent of the variation in machine productivity is caused by variation in overburden thickness. The new $t$ score indicates the probability that a direct relationship exists is approximately 95 per cent. This change strengthens the statement that a fairly strong relationship exists between average overburden thickness and selected machine productivity. This relationship also further explains the reason a direct relationship results between overburden thickness and labor productivity. Thicker overburdens result in larger stripping machinery being selected by the mining company, which, in turn, raises labor productivity.
TABLE 7
REGRESSION OF OVERBURDEN THICKNESS ON STRIPPING MACHINE EARTH-MOVING CAPACITY FOR CURRENTLY OPERATING NORTH DAKOTA SURFACE COAL MINING COMPANIES, 1955 TO 1975

<table>
<thead>
<tr>
<th>Company Number</th>
<th>Machine Capacity (Cubic Yards Per Hour) Y</th>
<th>Overburden (Feet) X</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,212</td>
<td>65</td>
</tr>
<tr>
<td>2</td>
<td>420</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>3,283</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>717</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>1,800</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>540</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>4,200&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>1,489</td>
<td>55</td>
</tr>
<tr>
<td>9</td>
<td>1,785</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>1,038</td>
<td>60</td>
</tr>
<tr>
<td>11</td>
<td>250</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>N/A&lt;sup&gt;b&lt;/sup&gt;</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Results

\[
Y = 494.0 + 20.0X
\]
Dependent variable: machine capacity
Independent variable: overburden thickness

\[
r = 0.37
r^2 = 0.13
t = 1.176
\]

Without (a):

\[
Y = 202.6 + 20.7X
\]

\[
r = 0.53
r^2 = 0.28
t = 1.804
\]

SOURCE: Mining companies.

<sup>a</sup>An unusually productive pan scraper operation.

<sup>b</sup>Not available.
Results: Ricardian Rent (Chi Square Test)

The remainder of the chapter describes the relationship existing between the sampled North Dakota mines, as they are ranked by market organization, and the criteria of the theory of discriminative selection. The theory suggests that mines with the highest labor productivity, thickest coal seams, thinnest overburden, and largest machinery investment can be associated with integrated companies. Mines with medium labor productivity, moderate coal seam and overburden thicknesses, and average stripping machine size may be associated with interstate and intrastate companies. Mines with lowest labor productivity, thinnest coal seams, thickest overburden, and smallest machinery are associated with single mine companies. Classifications of above average, average, and below average are based on how the data ranks in relation to the state average. Above average is 25 per cent and above the state average. Below average is 25 per cent or more below the state average.

Company Type and Average Physical Product of Labor

Table 8 is a cross tabulation of company type and the ranked labor productivity of the mines. The tabulated data shows that the smaller, single mine companies have a strong grouping in the "below average" class of labor productivity. The integrated and interstate companies are better off with labor productivity solidly "average" or "above average." Intrastate companies hold a weaker average position being split with one company's labor productivity rating "above average" and the other rating "below average." This distribution indicates that larger companies tend to have higher productivity of labor.
TABLE 8
CROSS TABULATION OF AVERAGE PHYSICAL PRODUCT OF LABOR
BY COMPANY TYPE FOR CURRENTLY OPERATING
NORTH DAKOTA SURFACE COAL MINE
COMPANIES, 1955 TO 1975

<table>
<thead>
<tr>
<th>Type of Company</th>
<th>Average Physical Product of Labor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Below Average</td>
</tr>
<tr>
<td>Integrated</td>
<td>0</td>
</tr>
<tr>
<td>Interstate</td>
<td>0</td>
</tr>
<tr>
<td>Intrastate</td>
<td>1</td>
</tr>
<tr>
<td>Single</td>
<td>4</td>
</tr>
</tbody>
</table>

Results

\[ x^2 = 10.8 \]
\[ n = 12 \]
\[ d.f. = 6 \]

Probability value = 89 per cent
Cramer's V = 0.67
State average = 53.9 tons per man per day

The probability that this relationship exists, as indicated by the chi square
statistic, is 89 per cent. This is a rather strong relationship. Cramer's V
statistic further supports this statement with a figure of 0.67 with 0.0
indicating no relationship and 1.0 indicating a perfect relationship exists.

Company Type and Coal Seam Thickness

Comparing company type to seam thickness results in an even stronger
relationship. Table 9 shows that no integrated companies fall below the
TABLE 9
CROSS TABULATION OF COAL SEAM THICKNESS BY COMPANY TYPE
FOR CURRENTLY OPERATING NORTH DAKOTA SURFACE
COAL MINE COMPANIES, 1955 TO 1975

<table>
<thead>
<tr>
<th>Type of Company</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Interstate</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Intrastate</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Single</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

Results

\[ x^2 = 12.8 \]
\[ n = 12 \]
\[ d.f. = 6 \]

Probability value = 95 per cent
Cramer's V = 0.73
State average = 12.8 feet

"above average" group. The other classifications seem to favor an "average" seam thickness. Apparently, single companies are not left with the thinnest seams. The one mine which had the thinnest coal seam in the census was a farmer who mined coal for three months per year to produce heating coal for himself and neighbors. The other companies have continuous supply commitments. The probability that this relationship exists is 95 per cent--a high figure. Cramer's V statistic confirms this probability for a strong
relationship between company size and coal seam thickness with an index of 0.73. This indicates the coal seam thickness is important in the reserve selection process.

**Company Type and Overburden Thickness**

Overburden thickness is important to all mining companies as Table 10 indicates. The largest companies (integrated) have totally avoided mining in deep overburdens, with one company ranking "below average" and one "average." Interstate companies also demonstrate a concentration towards thinner overburdens although they do not have a mine with below average thicknesses. The smallest companies are spread across the range of possibilities with a concentration in "average" overburden thicknesses. One explanation for this effect is that all the small companies started operation with thin overburdens as finances did not allow large stripping equipment. As mining progressed, the small companies grew and used the easiest mined reserves first. The small mines remaining which have the thinnest overburdens are those which did not grow or mine their reserves as fast; consequently, they are still mining in the original geological configurations in which they began.

The distributed data prevents the statistics from indicating clear trends. The probability that a strong relationship between company size and overburden thickness exists is only 17 per cent. Cramer's V follows suit with an index of 0.36.
TABLE 10
CROSS TABULATION OF OVERBURDEN THICKNESS BY COMPANY TYPE
FOR CURRENTLY OPERATING NORTH DAKOTA SURFACE
COAL MINE COMPANIES, 1955 TO 1975

<table>
<thead>
<tr>
<th>Type of Company</th>
<th>Overburden Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Below Average</td>
</tr>
<tr>
<td>Integrated</td>
<td>1</td>
</tr>
<tr>
<td>Interstate</td>
<td>0</td>
</tr>
<tr>
<td>Intrastate</td>
<td>1</td>
</tr>
<tr>
<td>Single</td>
<td>1</td>
</tr>
</tbody>
</table>

Results

\[ x^2 = 2.8 \]
Probability value = 17 per cent

\[ n = 12 \]
Cramer's V = 0.36

\[ \text{d.f.} = 6 \]
State average = 53.4 feet

Company Size and Stripping Machine Size

Finally, comparing machine size, there appears to be a trend visible in Table 11 indicating that larger companies have larger equipment than single mine companies; however, they do not select the largest equipment. Integrated companies are found to have thinner overburdens in the preceding section. Consequently, the large companies would not be expected to have the largest machinery. They have no listing in "above average" for machinery. The intermediate companies are evenly distributed across the machine-size
Table 11
CROSS TABULATION OF STRIPPING MACHINE CAPACITIES BY COMPANY TYPE FOR CURRENTLY OPERATING NORTH DAKOTA SURFACE COAL MINE COMPANIES, 1955 TO 1975

<table>
<thead>
<tr>
<th>Type of Company</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Interstate</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Intrastate</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Single</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Results

\[ x^2 = 3.8 \]

Probability value = 29 per cent

\[ n = 12 \]

Cramer's V = 0.41

\[ \text{d.f.} = 6 \]

State average = 1,521.3 cubic yards per hour

Categories. This indicates they are likely to be more flexible in their reserve acquisition and are mining in a broad range of overburden thicknesses. This is also indicated in Table 10 by their distribution in overburden categories. Single mine companies characteristically are small and are not likely to have capital or demand to require large efficient stripping machines. In practice, they are likely to operate with older or less costly machinery. The one company ranking in the "above average" classification is a particularly
productive pan scraper utilization scheme. Although this mine moves overburden quicker than any other system employed in the State, it is somewhat more labor intensive. This additional labor lowers productivity of labor and, therefore, does not show up in Table 8.

Because of the apparent avoidance of large strippers, the probability that a relationship exists between company size and equipment size is low at 29 percent. Cramer's V reflects this relationship with an index of 0.41.

Conclusion

This chapter presented the statistical results of two major investigations. The first investigation advanced the relative influences which the factors of production have in determining labor productivity. The second investigation was conducted to determine if the coal mining companies in North Dakota capture Ricardian differential rents by means of the discriminative selection of coal reserves.

The first investigation produced results which were contradictory to the hypotheses presented in Chapter IV. Coal seam thickness, when compared with labor productivity, produced results which indicate that a strong relationship does not exist. The direct relationship does indicate that coal seam thickness does somewhat predict labor productivity. The comparison of overburden and the productivity of labor produced unexpected results. Contrary to the hypothesis, a direct and strong relationship exists. Since an increase in overburden would be expected to lower labor productivity, further comparisons were made to find an explanation. Machine size was found to be
the important variable. Direct relationships were found to exist among machine size, overburden thickness, and labor productivity. The conclusion is that as overburden occurs in greater thicknesses, larger equipment (which tends to be labor efficient) is selected by the mining company. The result is higher labor productivity demonstrating a positive association with overburden thickness. Overburden thickness, then, can serve as a predictor of labor productivity and, to a lesser degree, machine size.

The second investigation attempted to detect the capture of Ricardian rent by the North Dakota coal mining companies. The results of these statistical tests support the hypotheses presented in Chapter IV. The statistics do not support a strong relationship between company type and overburden or company type and machinery size. Tabular data indicates all companies avoid thick overburdens with varying success. Machinery size conforms to national trends where smaller companies use small machinery and larger companies use larger but not the largest machinery available. Based on the findings pertaining to company type, average product, and seam characteristics, the conclusion can be made that larger companies have higher productivity, seek the thickest coal seams, and restrict operations to thinner overburdens. Small companies have lower productivity, mine average coal seams, and work in average overburden thicknesses. In both cases, larger machinery is avoided with mining being performed with machinery that may be most totally utilized. Small companies operate with less costly machinery. The results, therefore, provide a reasonable indication that Ricardian rents are being captured by the larger mining companies.
A final consideration is necessary because the nature of the data prohibits conclusive findings. Assuming the data is representative of the industry, the average physical product of labor may be predicted with a moderate degree of certainty using overburden data and information concerning the type of mining company intending to mine the reserve. Resource characteristics also indicate the company size most likely to extract the resource. Only finely detailed information covering shorter time spans will provide the exactness required for accurate prediction.
CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Introduction

This chapter is divided into three major sections. The first section includes a general summarization of the major topics developed in the preceding chapters. The second section contains a reassessment of conclusions made in this investigation of North Dakota strip mining. The last section contains recommendations for the State of North Dakota, mining companies, and professional economists.

Summary

Chapter II

Chapter II is a survey of the lignite surface mining industry, especially as it applies to North Dakota. The chapter begins with a geological description of lignite coal and its occurrence in the State which includes a comparison to other general-use coals. A brief discussion of the historical development of the North Dakota lignite industry and its marketing procedure follows. Next, the procedure for opening a new mine, as well as the actual mining process is discussed. Special attention is given to the influences of geology on mining decisions. Also, two typical mines are described; one mine is typical of those
producing over a million tons of coal per year, and the other is typical of mines with production less than half as great. Chapter II concludes with the comparison and contrasting of deep and surface mining with respect to differences in safety and productivity of miners. The discussions in this chapter provide a background for the theoretical development of mining economics contained in the following chapters.

Chapter III

Chapter III is a survey of economic theory and literature applicable to surface mining for the determination of influences which affect average product and the detection of Ricardian rent. The chapter is divided into three major sections: the mining problem and production theory, the re-examination of the factors of production in terms of strip mining techniques, and a review of supporting literature. The topics presented here establish the theoretical framework on which the practical investigations of later chapters are based.

The first section begins with a historical discussion of fixed proportion production theory which is appropriately used to investigate the land based production process of mining. The concept of productivity measurement is also discussed to provide an explanation for the use of labor productivity data in Chapter V. This introduction is followed by the analytical description of the resource extraction production function. Particular attention is given to the fixed proportion characteristics of land, labor, and capital in the surface mining process. The concept of fixed proportioned resources is further explained by the presentation of the concept of limitationality.
proportion nature of mining resources established, the concept of variable land
is presented.

Variable land provides the basis for the two major investigations of the
study. First, natural variations of the land quality are indicated to affect the
average product of the mining operation. Theoretical evidence is used to
demonstrate that, given a fixed combination of labor and capital, productivity
varies according to the endogenous qualities of the land resource. Second,
the variability of the land resource provides an opportunity for the application
of the Ricardian theory of differential rent. By slightly modifying this theory,
the process of discriminative selection of coal reserves by mining companies
is explained. Incentives for discriminative selection are lower mining costs
and higher productivity. The practical investigation of these theories are
contained in Chapter V.

The second section of Chapter III examines the special theoretical
characteristics of the factors of production employed in the surface mining
process. Land, the first factor investigated, is divided into two aspects:
coal seam thickness (fertility) and overburden thickness (a barrier).
Variations of the two qualities are suggested as key influences of fluctuations
in labor productivity and reserve selection.

The second factor investigated, capital, represents two investments
for mining companies. The first investment is extraction machinery which,
when combined with labor in a fixed proportion, is resistant to variation after
the initial employment. The second investment considered is company
organization for operation. This form is the organization pattern assumed by
the mining company for the purposes of marketing coal and maximizing its own
financial position. A four-level classification scheme, based on operational
size of the company, is used to test this factor. Named by increasing size is:
the single mine company, the intrastate company, the interstate company, and
the integrated company.

Labor is the third factor investigated. Its importance in the engineered
combination with capital and as a measurement of production is explained.
Changes in labor productivity are important because the measurements reflect
influences of variable land, in the short run, and variations in capital
investments, in the long run.

The second section of Chapter III is concluded with a discussion of the
producers production set. This concept ties the preceding factor
characteristics into a single package. The interaction of variable land, with
the fixed proportion of labor and capital, is explained. The effects of this
interaction on output and the occurrence of efficient resource allocation within
a range of attainable production possibilities is illustrated.

The final section of Chapter III is a presentation of three previous studies
in mining economics. These selections represent specific attempts to
investigate surface and deep mining with respect to the factors of production
and trends in productivity. The earliest study is by Hubert E. Risser and
investigates changes in the mining industry from 1903 to 1953. He uses the
average physical product of labor as an index of change. This index enables
him to make important predictions concerning changes in technology and the future of surface-mined coal. Risser also successfully investigates the mining companies in an attempt to detect if they capture Ricardian rents.

A second study is undertaken by Carol L. Christenson who focuses on coal industry changes from 1930 to 1960. His investigation also attempts to find indications of Ricardian rents drawn by larger companies. He determines larger companies have the best coal reserves, the highest productivity, and the larger share of the coal market.

The third study reviewed was produced by Scot A. Stradley in 1977 and is particularly oriented towards the Utah deep mine coal industry. His study is particularly strong with respect to the theoretical presentation of mining economics and production theory. He evaluates mine productivity and investigates its association with the factors of production. Indications of Ricardian rents derived by large mining companies are investigated. S. Stradley concludes his investigation with the statement of the Utah coal mine production function and predicts labor demand for the State, based on his findings of the relationship among factors of production.

The limitations of these studies are noted particularly for their lack of attention to the lignite mining industry. The increased importance for strip mined coal in providing an alternative power source necessitates its investigation.
Chapter IV

Chapter IV presents the hypothesized factor relationships which are statistically tested in Chapter V. The format conforms to the two important purposes of the study. First to be investigated are likely determinants of labor productivity, and second to be investigated is the concept of Ricardian rent in the form of discriminative selection of coal reserves by mining companies.

In the investigation of the determinants of labor productivity, coal seam thickness is thought to be directly related to the average product of labor. The opposite relationship is suspected to be the case when comparing overburden thickness and labor productivity. Investment capital, the capital invested in production machinery, is hypothesized to have a direct relationship to labor productivity. These hypotheses are tested in Chapter V utilizing simple regression techniques.

The second investigation, intended to detect Ricardian rents, compares organization capital, that capital employed in marketing coal, to labor productivity. Assuming large companies attract economic rents through improved marketing capabilities and financial strength, they are hypothesized to produce coal with a higher level of labor productivity than smaller companies. Organization capital is also compared with geological characteristics and machinery indexes. The hypothesized relationship of company type and geological characteristics involve advantageously mined reserves. Large companies mine thicker coal seams and thinner, more easily penetrated overburdens. Larger companies are likely to mine with larger and more
efficient machinery. These ideas are tested in Chapter V using the chi square test of independence. Confirmation of the hypotheses indicates that large companies enjoy a favored production position and capture Ricardian rents.

Chapter V

Chapter V contains the actual statistical testing of the hypotheses presented in Chapter IV. Two basic statistical tests are used: simple linear regression, to test the ability of the factors of production to determine labor productivity, and the chi square test of independence, to test for the presence of Ricardian rents.

The regression analysis between coal seam thickness and labor productivity indicates that a weak, direct relationship is present. The statistical test between overburden and labor productivity indicates, contrary to the hypothesis, that a direct relationship exists. The statistical test of machine size and labor productivity produce a direct relationship of appreciable strength. To further explain the results of the unexpected association between overburden and labor productivity, a third test is performed which completes the triangular test pattern. In this test, the machine productivity index is compared to overburden thickness. The results indicate a direct relationship is present. The explanation of the unexpected results between overburden and labor productivity, therefore, lies with the influence of machine size.

The investigation for indications of Ricardian rents produces results which conform to the hypotheses proposed in Chapter IV. Results of the chi square analysis indicate large companies may indeed have higher labor
productivity as well as advantages of better quality coal reserves and larger, more productive machinery. All companies, regardless of size, seem to avoid thick overburden. The statistical tests indicate that Ricardian rents are likely being obtained by larger mining companies.

**Conclusions**

Based on the results of this investigation of the North Dakota lignite industry and the factors of production, a number of conclusions may be made. The survey of the lignite mining industry of North Dakota provides a reminder that lignite is a promising alternative fuel for easing the gas and oil shortage facing the United States. It is a relatively clean-burning and easily obtained fuel. Because of its abundance in North Dakota, expansion of the lignite industry is inevitable. The utilization of the fuel in a mine-mouth setting for electrical generation and the manufacture of synthetic natural gas will cause labor migrations to the small towns which are near the mines. To properly prepare for this economic and social impact, more information is needed concerning the relationship of the coal resources and labor demand.

Geological and market conditions determine the scale of production at which North Dakota lignite mines operate. Although national trends indicate thinner coal reserves remain, larger machinery has effectively raised labor productivity. Improved blasting ratios and stripping ratios occur because of the advancement of technology. Within constraints of safety and mining legislation, mine workers are able to produce enough coal to meet rising demands. The interrelationship of these factors is important to the
determination and continual monitoring of social and economic impact attributable to mine expansion.

Fixed factor production theory is appropriate for explaining the economics of resource extraction. Economists have generally overlooked these land based production processes by devoting energies to variable factor production processes typical of manufacturing situations. The factors of production in surface mining are geologically, and to a lesser degree, demand determined. Geology of the reserve determines the type of equipment appropriate for mining and demand influences the scale of operation. The machine (capital) and manpower (labor) combination is fixed; that is, a machine is built to be operated by a specific quantity of labor. This ratio of man to machine varies little. The productivity of labor modulates across the North Dakota coal mining industry. The labor/capital ratio remains fixed in the short run; therefore, the variations are explained by a variable land resource. Natural occurrences of coal seam thickness and overburden thickness are responsible for changes in labor productivity since thicker coal seams increase productivity and thicker overburdens require larger machinery which, in turn, increases productivity. Only in the long run are labor productivity changes attributable to technological changes (different labor/capital combinations).

The importance of the variable land resource is evident when investigating mining companies for the presence of Ricardian rents. The theory of discriminative resource selection indicates the mining companies select among the available reserves in an attempt to mine the best reserves
first. Larger companies, with greater economic strength and bargaining power, tend to obtain better reserves than smaller companies. Consequently, the larger companies maintain higher labor productivity and draw Ricardian rents. Small companies remain disadvantaged and, through time, either stop mining or exploit non-competing coal markets.

Knowing relationships of the factors of production to labor productivity and corporate characteristics is important for determining labor demands and regional impact for the mining region. The statistical investigation contained in Chapters IV and V indicates the most important resource characteristic for predicting labor productivity is overburden thickness. The overburden thickness is a strong determinant of machine size which, in turn, is a strong determinant of labor productivity. As overburden becomes thicker throughout the surface mined lignite industry, larger machinery is selected. The larger equipment produces higher labor productivity.

Further statistical results imply the large companies tend to have high labor productivity compared to the rest of the North Dakota coal industry. A conclusion, therefore, is: the efficient production afforded by larger machinery is generally captured by the larger mining companies. The ability to obtain the high capital investment likewise enables the larger companies to seek out high demand contracts; high output is important for making the large equipment cost-effective. Of the easily obtained coal reserves, thicker lignite seams are generally located under thicker overburdens. This necessitates large extraction machinery for resource recovery which, again, larger companies are able to economically employ.
Smaller companies, on the other hand, seem to obtain less productive coal reserves. This has the effect of limiting the demand that can be filled. Lower capital investments generally indicate lower labor productivity and less economical production. To remain in business, the small companies seek specialized coal markets exemplified by retail sales, charcoal briquetting, or oil well drilling mud stabilizers. The trend in North Dakota, however, has been for the small operator to stop mining or go out of business.

Knowing these relationships can allow the government to plan properly for economic growth and labor migrations in regions affected by coal development. Geological characteristics of the coal reserve allow assumptions to be made concerning the type of company that might obtain mining rights and the kind of demand the company might fill. Knowing the output potential of the mine and the machinery necessary for producing that output will also indicate the productivity of the labor employed. This, finally, can provide indications of labor demand and the resulting regional impact.

**Recommendations**

Recommendations that can be made as a result of this study fall into three main areas: recommendations for economists, recommendations for mining companies, and recommendations to State government. Economists should be aware of the mining industry because it represents an opportunity to address the theories of fixed factor production. Little attention has been given to the land based industries. Variable factor production theory is appropriate for a manufacturing setting; however, when nature is involved, constraints are made
on the production process which cannot be infinitely varied. Effects of weather, geological occurrences of resources, and natural barriers to the resource are important to production. Machinery, in many cases, requires fixed allocations of labor for its operation. Labor cannot be varied to raise production. Rather, additional labor/capital combinations must be utilized. This concept needs greater development.

Mining companies in North Dakota have been cooperative in providing a great deal of information for this study. There is, however, an apparent overriding protectiveness. Lignite mining is rapidly expanding in North Dakota and, in many ways, will affect the general populous of the State. The acquisition of adequate information is necessary to prepare for this growth. The lignite industry might well consider utilizing the North Dakota Lignite Council as an information agency as well as a lobbying agency. This office could be a central clearing house for production data which is important for future research. The difficulty of obtaining detailed information about the mining industry is recognized even by the National Coal Association. (1977) The Lignite Council might also act as a protective guardian of information which the coal industry might regard as sensitive. The Council also would be able to help eliminate the persistent interruption of administrative mine personnel caused by information seekers. The proper utilization of the Lignite Council would well improve mining company public relations.

The North Dakota Government should also be interested in improved data acquisition. Proper legislation which prepares the State for regional impact.
and western community development requires concise data. The North Dakota State Mine Inspectors reports have been extremely valuable in the preparation of this study. The deterioration of the quality of these reports in the last three years has contributed to the inaccuracies of this investigation. As a result, less reliable information had to be obtained from other sources. Taxation of mining companies requires better information of reserve estimates and coal values. The impact of the coal industry must be properly assessed and adversely affected people must be compensated. Proper taxation provides the assurance that the coal companies pay their fair share.
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